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COGENERATION TECHNOLOGY ALTERNATIVES STUDY (CTAS) UNITED TECHNOLOGIES CORPORATION FINAL REPORT

VOLUME IV – HEAT SOURCES, BALANCE OF PLANT, AND AUXILIARY SYSTEMS

**Power Systems Division
United Technologies Corporation**

January 1980

**Prepared for
NATIONAL AERONAUTICS AND SPACE
ADMINISTRATION
Lewis Research Center
Under Contract DEN3-30**

**for
U.S. DEPARTMENT OF ENERGY
Energy Technology
Fossil Fuel Utilization Division**



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COGENERATION TECHNOLOGY ALTERNATIVES STUDY (CTAS)

UNITED TECHNOLOGIES CORPORATION FINAL REPORT

DOE/NASA/0030-80/4

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January 1980

Volume IV

Heat Sources, Balance of Plant and Auxiliary Systems

Prepared for

**National Aeronautics and Space Administration
Lewis Research Center
21000 Brookpark Road
Cleveland, Ohio 44135**

Under Contract No. DEN3-30

for

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Energy Technology
Fossil Fuel Utilization Division
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Peter Bolan

Program Manager



**UNITED
TECHNOLOGIES.
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15. Supplementary Notes Final Report, Prepared Under Interagency Agreement EC-77-A-31-1082. Project Managers, G. Barnes and J. Dunning, Power Generation and Storage Division, NASA Lewis Research Center, Cleveland, Ohio 44135.			
16. Abstract <p>The Cogeneration Technology Alternatives Study (CTAS) provides data and information in the area of advanced energy conversion systems for industrial cogeneration applications in the 1985-2000 time period. Six current and thirty-one advanced energy conversion systems were defined and combined with appropriate balance-of-plant equipment. Twenty-six industrial processes were selected from among the high energy consuming industries to serve as a frame work for the study. Each conversion system was analyzed as a cogenerator with each industrial plant. Fuel consumption, costs, and environmental intrusion were evaluated and compared to corresponding traditional values. Various cogeneration strategies were analyzed and both topping and bottoming (using industrial by-product heat) applications were included.</p> <p>The advanced energy conversion technologies indicated reduced fuel consumption, costs, and emissions. Typically fuel energy savings of 10 to 25 percent were predicted compared to traditional on-site furnaces and utility electricity. With the variety of industrial requirements, each advanced technology had attractive applications. Overall, fuel cells indicated the greatest fuel energy savings and emission reductions. Gas turbines and combined cycles indicated high overall annual cost savings. Steam turbines and gas turbines produced high estimated returns. In some applications, diesels were most efficient. The advanced technologies used coal-derived fuels, or coal with advanced fluid bed combustion or on-site gasification systems.</p> <p>This volume presents heat source, balance-of-plant, and plant design information developed by Bechtel National, Incorporated; heat storage data developed by Rocket Research Company; and heat pump information developed by Power Systems Division United Technologies with the advice of Westinghouse Electric Company</p>			
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VOLUME IV

PREFACE

The Cogeneration Technology Alternatives Study (CTAS) was performed by the National Aeronautics and Space Administration, Lewis Research Center, for the Department of Energy, Division of Fossil Fuel Utilization. CTAS is aimed at providing a data base which will assist the Department of Energy in establishing research and development funding priorities and emphasis in the area of advanced energy conversion system technology for advanced industrial cogeneration applications. CTAS includes two Department of Energy-sponsored/National Aeronautics and Space Administration-contracted studies conducted in parallel by industrial teams along with analyses and evaluations by the National Aeronautics and Space Administration's Lewis Research Center.

This document describes the work conducted by Power Systems Division of United Technologies Corporation under National Aeronautics and Space Administration contract DEN3-30. This United Technologies contractor report is one of a set of reports describing CTAS results. The other reports are the following: Cogeneration Technology Alternatives Study (CTAS) Volume I - Summary NASA TM 81400, Cogeneration Technology Alternatives Study (CTAS) General Electric Final Report NASA CR 159765-159770 and Cogeneration Technology Alternatives Studies (CTAS) Volume II - Comparison and Evaluation of Results, NASA TM 81401.

This United Technologies contractor report for the CTAS study is contained in six volumes:

- | | |
|------------|---|
| Volume I | - Summary Report, DOE/NASA/0030-80/1 NASA CR 159759 |
| Volume II | - Industrial Process Characteristics, DOE/NASA/0030-80/2
NASA CR 159760 |
| Volume III | - Energy Conversion System Characteristics, DOE/NASA/
0030-80/3 NASA CR 159761 |
| Volume IV | - Heat Sources, Balance of Plant, and Auxiliary Systems,
DOE/NASA/0030-80/4 159762 |
| Volume V | - Analytic Approach and Results, DOE/NASA/
0030-80/5 159763 |
| Volume VI | - Computer Data, DOE/NASA/0030-80/6 NASA CR 159764 |

The data and information presented in this Volume IV were developed by Bechtel National, Incorporated, of San Francisco, California and Rocket Research Company of Redmond, Washington in the conduct of the Cogeneration Technology Alternatives Study. Westinghouse Electric Company consulted in the development of the heat pump analysis by Power Systems Division, United Technologies.

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VOLUME IV

A. INTRODUCTION

The Cogeneration Technology Alternative Study evaluated the advantages of advanced energy conversion technologies in industrial cogeneration applications. To meet the objectives of the study, data and information had to be established for: (1) representative process plants in energy-intensive industries; (2) both current and future energy conversion technologies; (3) heat sources (or furnaces) as required by the conversion systems; (4) supporting technologies; (5) balance of plant; and (6) study assumptions and ground rules. These data were analyzed and conservation, economic, and environmental impacts were evaluated at the plant level and extrapolated to the potential national level.

The study in its entirety is summarized in Volume 1 of this report. A series of five additional volumes provide the more detailed data and information which was used in the course of the study.

This Volume IV presents the data for heat sources, balance of plant items, thermal energy storage, and heat pumps.

Section B includes descriptions of fourteen heat source design cases developed by Bechtel National Incorporated.

Section C contains the data concerning thermal storage systems provided by Rocket Research Company.

Section D contains descriptions of fourteen balance of plant systems developed by Bechtel National Incorporated.

Section E presents the projected performance of conceptual industrial heat pumps.

Section F presents the results of a review by Bechtel National, Incorporated, of the capital cost estimates for representative cogeneration plants which were selected from the more than 3000 cases considered in the study.

B. HEAT SOURCE DESIGN CASES

INTRODUCTION

This section describes operation, cost, and emission characteristics of the following fourteen heat source design cases:

<u>CASE NUMBER</u>	<u>CASE NAME</u>
1	Petroleum residual oil-fired, 140F water heater
2	Petroleum residual oil-fired, 300F steam generator
3	Petroleum residual oil-fired, 500F steam generator
4	Petroleum residual oil-fired, 700F steam generator
5	Petroleum residual oil-fired, 950F steam generator
6	Coal-derived residual oil-fired, 1050F steam generator
7	Coal-derived residual oil-fired, 1800F hot gas generator
8	Coal-derived residual oil-fired, 2200F hot gas generator
9	Coal-derived residual oil-fired, 2400F thermionic converter heat source
10	Coal-fired, 950F steam generator
11	Coal-fired atmospheric fluidized bed, 1050F steam generator
12	Coal-fired atmospheric fluidized bed, 1500F hot gas generator
13	Coal-fired pressurized fluidized bed, 1600F hot gas generator
14	Industrial waste heat recovery, 950F steam generator

Cases 1 through 5, 10, and 14 are current technology systems. The other cases are advanced technology systems which may be commercially available in the 1985 to 2000 time period.

Each of the 13 fueled heat sources is fired with petroleum boiler grade (Number 5 or 6) oil, coal-derived boiler grade oil, or high sulfur coal. The industrial waste heat recovery steam generator uses 1000F flue gas from an industrial process furnace.

Each heat source was designed for a thermal output capacity appropriate for the heat source configuration physical constraints and the capacity of the associated energy conversion system. The variation in heat source characteristics over a range of thermal output capacity was also developed for each case. The ranges of thermal capacity considered are 50 to 250 million Btu/hr for Cases 1 through 4, and 50 to 1000 million Btu/hr for Cases 5 through 14.

A descriptive section follows for each heat source design case. Each description includes a schematic diagram and list of characteristics which define the system. The design point thermal capacity, performance, and operating parameters are

presented as well as data for thermal efficiency and auxiliary power required as a function of system thermal output. All efficiencies are based on the higher heating value of the fuel. Each section also includes environmental intrusion data, flexibility and reliability characteristics, space requirements, maintenance requirements, capital and operating costs, installation requirements for heat sources with a range of output capacities. Environmental intrusion data are presented as a function of gross energy input to the heat source. All other data are expressed as a function of the energy output by the heat source. Cost data are presented in mid-1978 dollars.

Tables are included for each case showing breakdown of field construction costs for each of the heat sources defined for CTAS. Two tables are included for Cases 5, 6, 11 and 12, one representative of the shop assembled boilers used in smaller capacity systems and the other representative of field erected boilers used in larger systems. Two tables are included for Case 9, representing a high temperature ceramic air heater and an alternate without the ceramic air heater. Two tables are also included for Case 10, representing a stoker-fired and a pulverized coal-fired unit.

Hot Gas Generators Using Helium

The hot gas generators, Cases 7, 8 and 12, were designed to use air as the working fluid. Systems to heat helium instead of air would be similar except the heat exchange area would be reduced because helium has better heat transfer characteristics. The heat exchangers for each system were resized for helium so that the working fluid design pressure drop would be 0.5 percent instead of 2 percent which was used for air. The resulting reductions in heat source system field construction costs due to the smaller heat exchangers are as follows:

<u>Case</u>	<u>Cost Reduction</u>
7	9%
8	13%
12	5%

Heat Source Building Requirements

The cost of the buildings required to house heat source equipment were not included as part of the heat source system. The costs of these buildings were estimated using the building cost formula for balance-of-plant System 12. The approximate building requirements follow:

Cases 1, 2, 3, and 4:

Building area and volume required are same as the heat source area and volume which was provided previously.

Cases 5, 6, and 14:

Building volume required is 140 cubic feet per million Btu/hr heat output.

Cases 7, 8, and 9:

Building volume required is 150 cubic feet per million Btu/hr heat output.

Cases 10, 11, and 12:

Building volume required is 200 cubic feet per million Btu/hr heat output.

Case 13: No building required.

Where only volume is given, building height may be assumed to be 40 feet.

CASE 1
PETROLEUM RESIDUAL OIL FIRED, 140F WATER HEATER

The heat source system shown in Figure IV-1 uses a current technology petroleum residual oil fired boiler and direct contact water heater to produce 40 psig, 140F water. It is representative of current industrial practice for systems producing 50 to 250 million Btu/hr thermal output. The system's design and operating characteristics are as follows.

Characteristics

- Shop assembled, water tube, natural circulation boiler with water-cooled furnace walls for indoor installation
- Direct contact water heater
- Forced draft fan with inlet silencer
- Externally mounted windbox with steam atomizing fuel oil burner and duplex fuel oil system
- Externally located finned tube economizer to recover heat from boiler exit gases
- Flue gas damper to maintain natural draft
- Natural draft stack
- Three element feedwater control
- Mechanical linkage type fuel/air ratio control
- Stack gas oxygen content controls excess air
- Staged firing for nitrogen oxides emission control
- Manually operated soot blowers
- Building to enclose all major equipment

Design Point Performance

- Thermal output - 150 million Btu/hr
- Working fluid conditions
 - Inlet - 0 psig, 85F water
 - Outlet - 40 psig, 140F water
- Thermal efficiency - 88% (CTAS ground rule)

Operating Parameters

Table IV-1 gives the flowrate, temperature and pressure of each of the major streams in the system. The stream numbers are identified on the system schematic diagram.

Permissible Range of Operation

Figure IV-2 shows the variation in thermal efficiency over the permissible range of operation.

Effect of Capacity on Efficiency

Design point efficiency varies only slightly over the range of thermal output considered. The variation which is shown in Figure IV-3 is due to change in the radiation losses from the boiler.

Auxiliary Power Requirement

Electric power is required for the forced draft fan, boiler feedwater pumps, and process water pumps. The power requirement is shown as a function of thermal output in Figure IV-4.

Environmental Intrusion

Table IV-2 gives the stack gas emissions, wastes discharged, and requirements of water and atomizing steam for the heat source system. Data are expressed in pounds of material per million Btu gross energy input to the system (fuel higher heating value). Stack gas emissions were calculated on the basis of fuel specifications defined for this study.

Flexibility and Reliability

This current technology heat source for non-cogeneration applications represents a baseline system to which the advanced

technology cogeneration heat sources will be compared. Its characteristics are as follows.

- Fuel Flexibility. The heat source can be modified to fire a wide range of petroleum or coal derived distillate and residual oils as well as gaseous fuels of varying compositions and heating values. Modifications of the fans, ductwork and burner system would be required. Addition of an emission control system for sulfur or particulate removal might also be required for fuels with high sulfur or ash content.
- Transition to Coal or Coal Derived Fuel. Modifications of conventional oil fired units to accept coal firing is not practical due to the differences in combustion and heat release characteristics and fuel handling equipment required. However, coal derived gaseous and liquid fuels can be fired as described in the previous paragraph.
- Operational Flexibility. The unit may be operated from 20% to 110% of design thermal output with only a small change in efficiency.
- Retrofit to Existing Plants. Retrofit potential is good because space requirements are low and the system does not have special operational or safety problems.
- Retrofit of Technology Advancements. The system can be modified to incorporate advances in burner design and combustion air control technology.
- Siting Flexibility. The siting requirements are similar to those typical of an industrial plant. Rail access is required for construction and fuel delivery. Water must be available for boiler feed water makeup. However, the system has no special requirements which will influence siting flexibility.
- Potential Reliability. Reliability has been shown historically to be high. Multiple units can be used to increase reliability without large cost penalties because capital and operating costs are relatively insensitive to unit size.

The area and volume requirements for the heat source system are expressed as a function of the system thermal output capacity by the following equations,

$$\text{Area (sq ft)} = 1090 + 10.6C$$

$$\text{Volume (cu ft)} = 630C$$

where C is equal to the system thermal output capacity in million Btu/hr. The area and volume requirements do not include the exhaust stack.

Maintenance and Overhaul

Scheduled maintenance and overhaul frequencies for the heat source system and the associated planned outages are as follows.

	<u>Maintenance</u>	<u>Overhaul</u>
Interval	12 months	60 months
Planned Outage Required	1 week	4 weeks

Capital and Operating Costs

- Capital Cost. Figure IV-5 shows field construction costs versus thermal output for the heat source system. The costs are broken down into equipment and material cost and installation costs. Installation costs include direct installation labor at \$14.00 per manhour plus 75% of direct labor costs for indirect field costs (distributables). Table IV-3 presents the cost breakdown for a system designed for 150 million Btu/hr thermal output capacity.
- Operating and Maintenance. Annual operating and maintenance costs for the system exclusive of fuel costs are estimated at \$175 per million Btu/hr design thermal output capacity of the heat source.

Construction and Installation Period

A period of approximately two months would be required for construction and installation of the heat source system for the range of sizes considered.

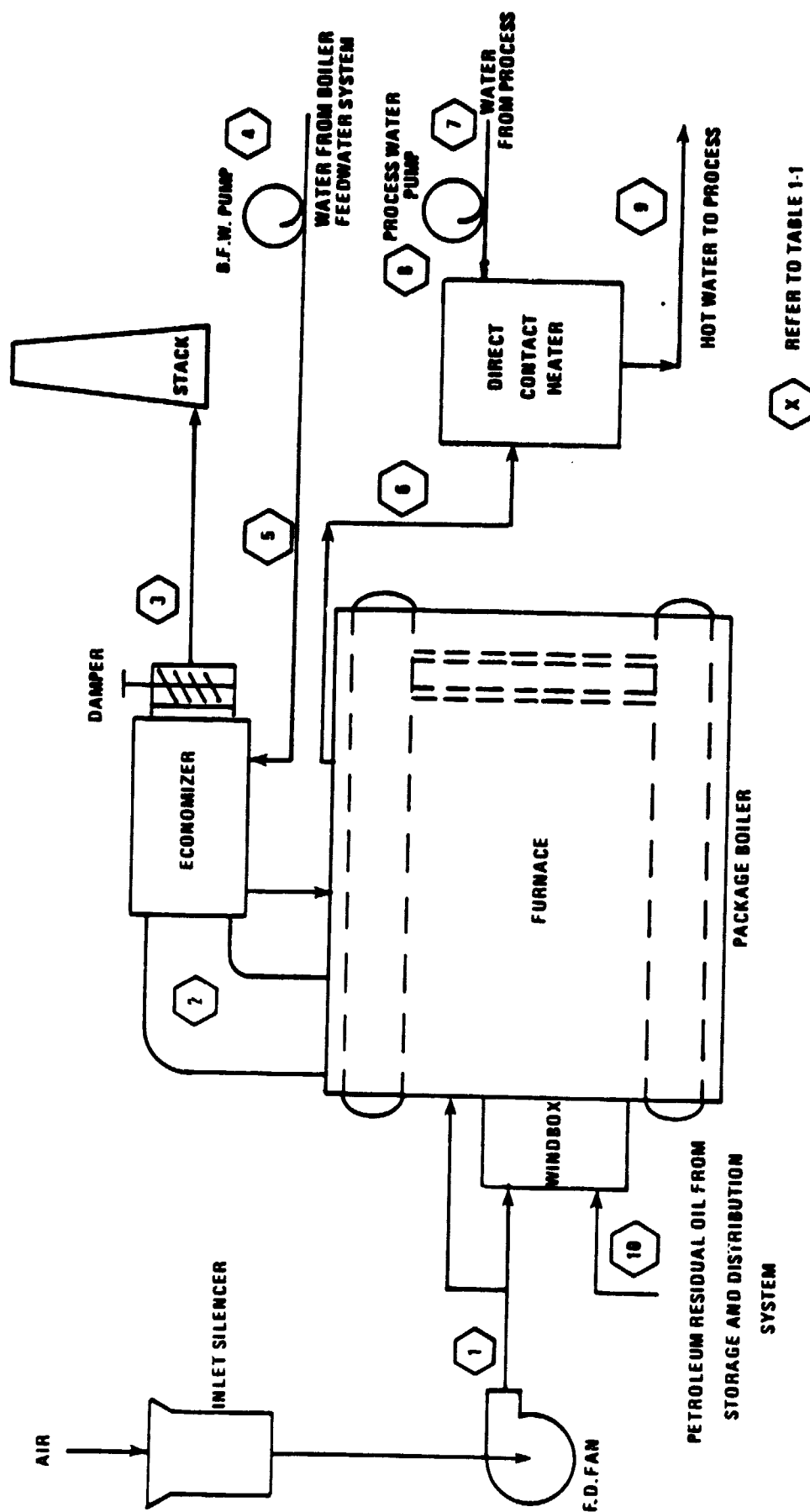


Figure IV-1 PETROLEUM RESIDUAL OIL FIRED, 140F WATER HEATER

TABLE IV-1

PETROLEUM RESIDUAL OIL FIRED, 140F WATER HEATER

OPERATING PARAMETERS

(150 MILLION BTU/HR)

<u>Stream Number</u>	<u>Flowrate (lb/hr)</u>	<u>Temperature (F)</u>	<u>Pressure (psia)</u>
1	146,800*	59	15.6
2	156,000	400	14.8
3	156,000	300	14.7
4	157,600	250	30.0
5	157,600	250	75.0
6	156,000	298	65.0
7	3,040,000	85	15.0
8	3,040,000	85	60.0
9	3,196,000	140	55.0
10	9,200	120	70.0

* 15% Excess Combustion Air

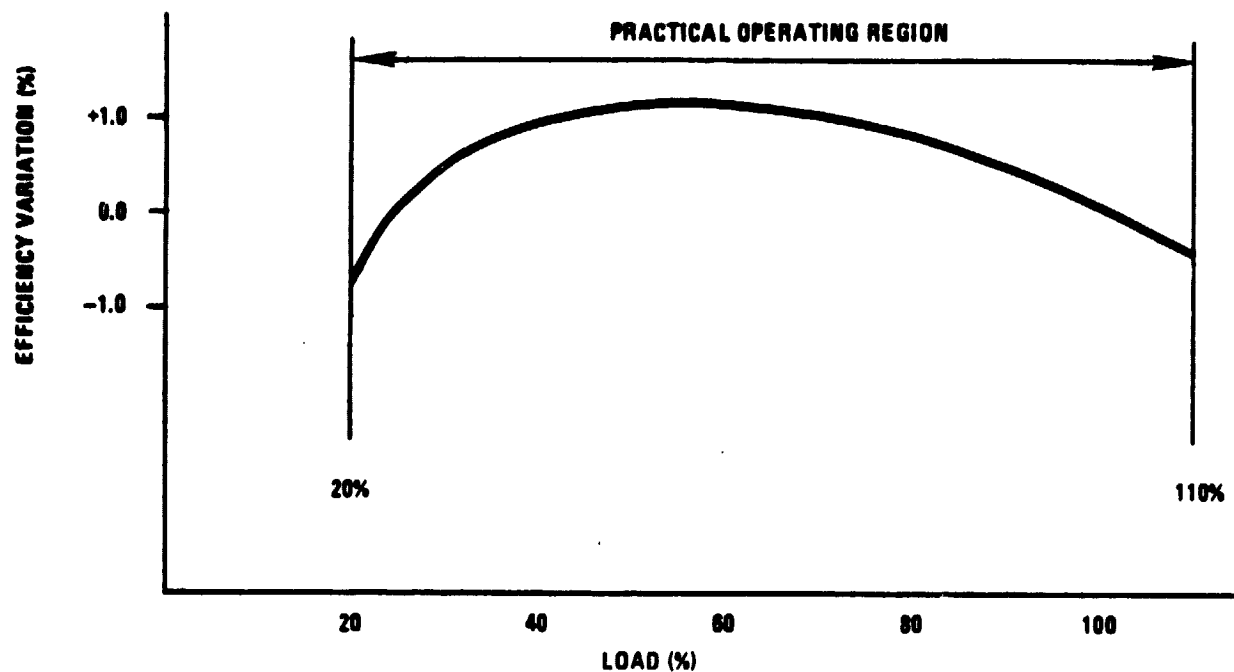


Figure IV-2 VARIATION OF THERMAL EFFICIENCY WITH PERCENT LOAD FOR THE PETROLEUM RESIDUAL OIL FIRED, 140 F WATER HEATER

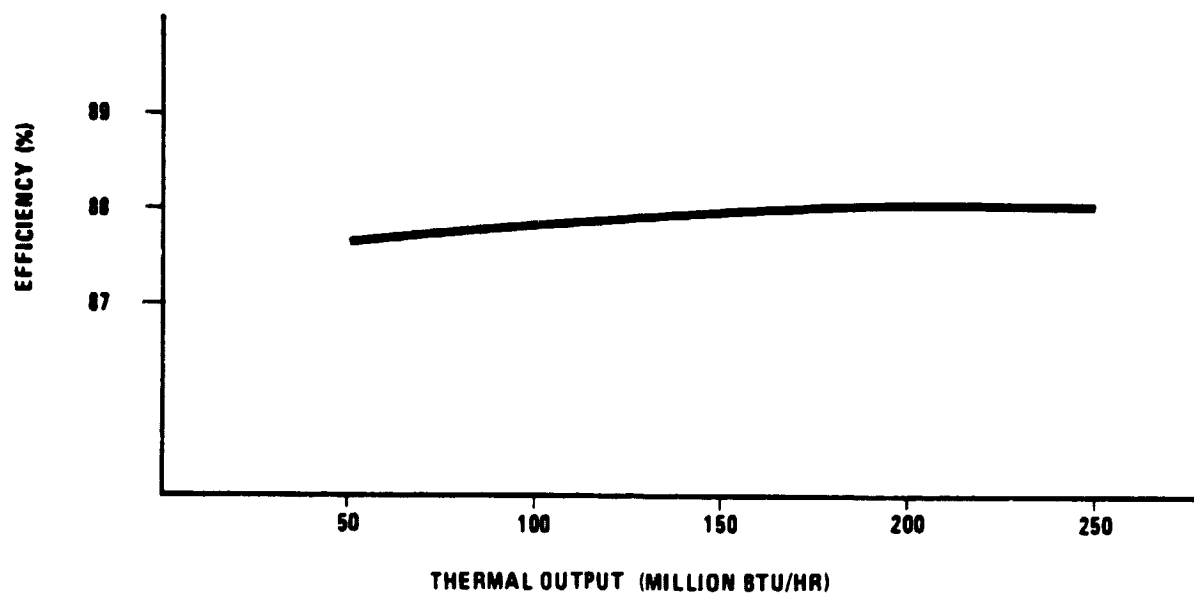


Figure IV-3 VARIATION OF DESIGN POINT EFFICIENCY WITH DESIGN POINT OUTPUT FOR PETROLEUM RESIDUAL OIL FIRED, 140 F WATER HEATER

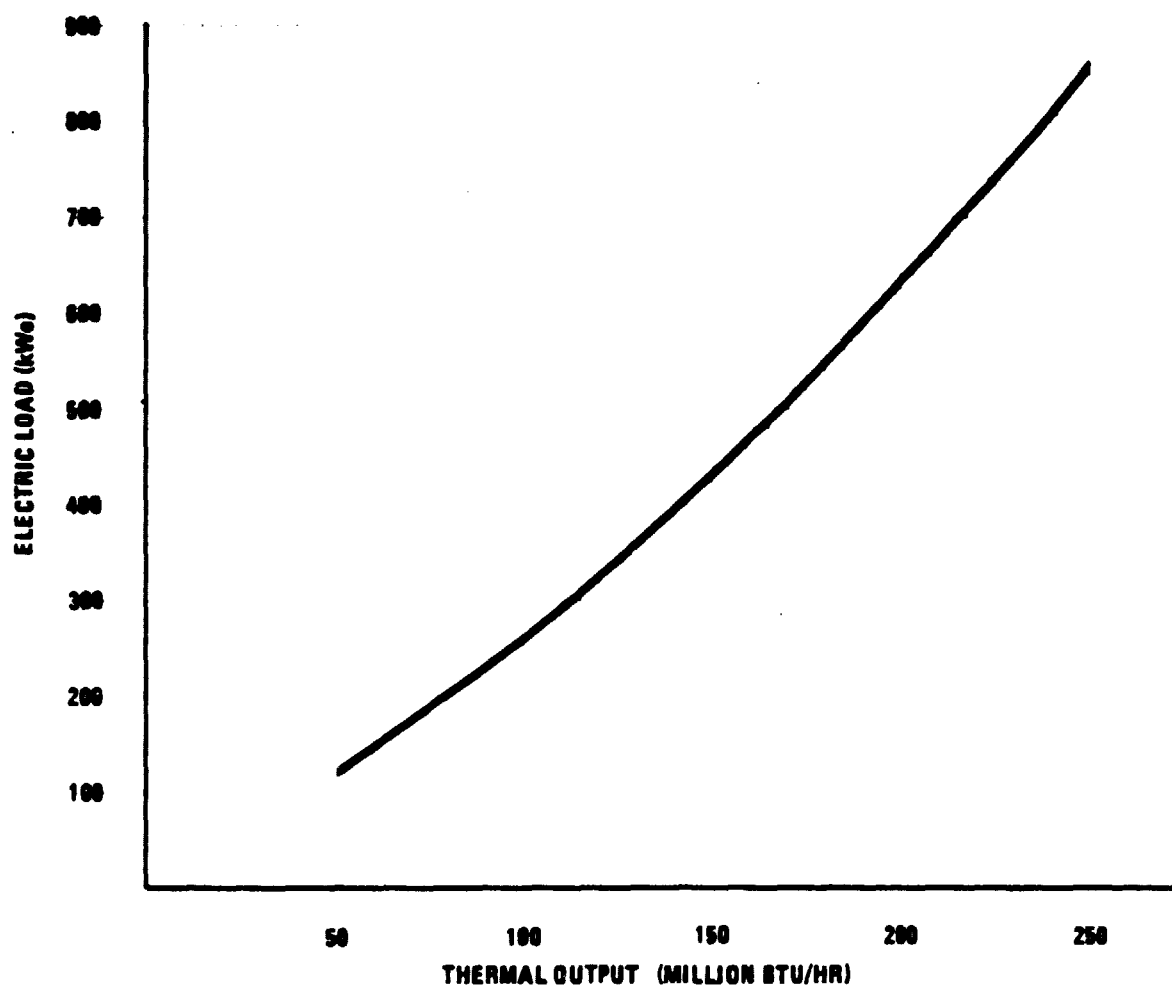


Figure IV-4 VARIATION OF AUXILIARY POWER REQUIRED WITH THERMAL OUTPUT
FOR THE PETROLEUM RESIDUAL OIL FIRED, 140 F WATER HEATER

TABLE IV-2

PETROLEUM RESIDUAL OIL FIRED, 140F WATER HEATER
ENVIRONMENTAL INTRUSION

<u>Stack Gas Emissions</u>	<u>Predicted Rate (lb/million Btu)</u>
Sulfur Dioxide	0.76
Nitrogen Oxides	0.5
Hydrocarbons	0.02
Carbon Monoxide	0.027
Particulates	0.016
<u>Wastes Discharged</u>	
Water (Blowdown)	9.3
Dry Solids	0
Wet Solids	0
<u>Water Required</u>	
(Exclusive of Boiler Feed Water)	0
<u>Steam Required (50 psig, 300F Condition)</u>	
Fuel Atomizing	17.6

COST IN MID-1978 DOLLARS

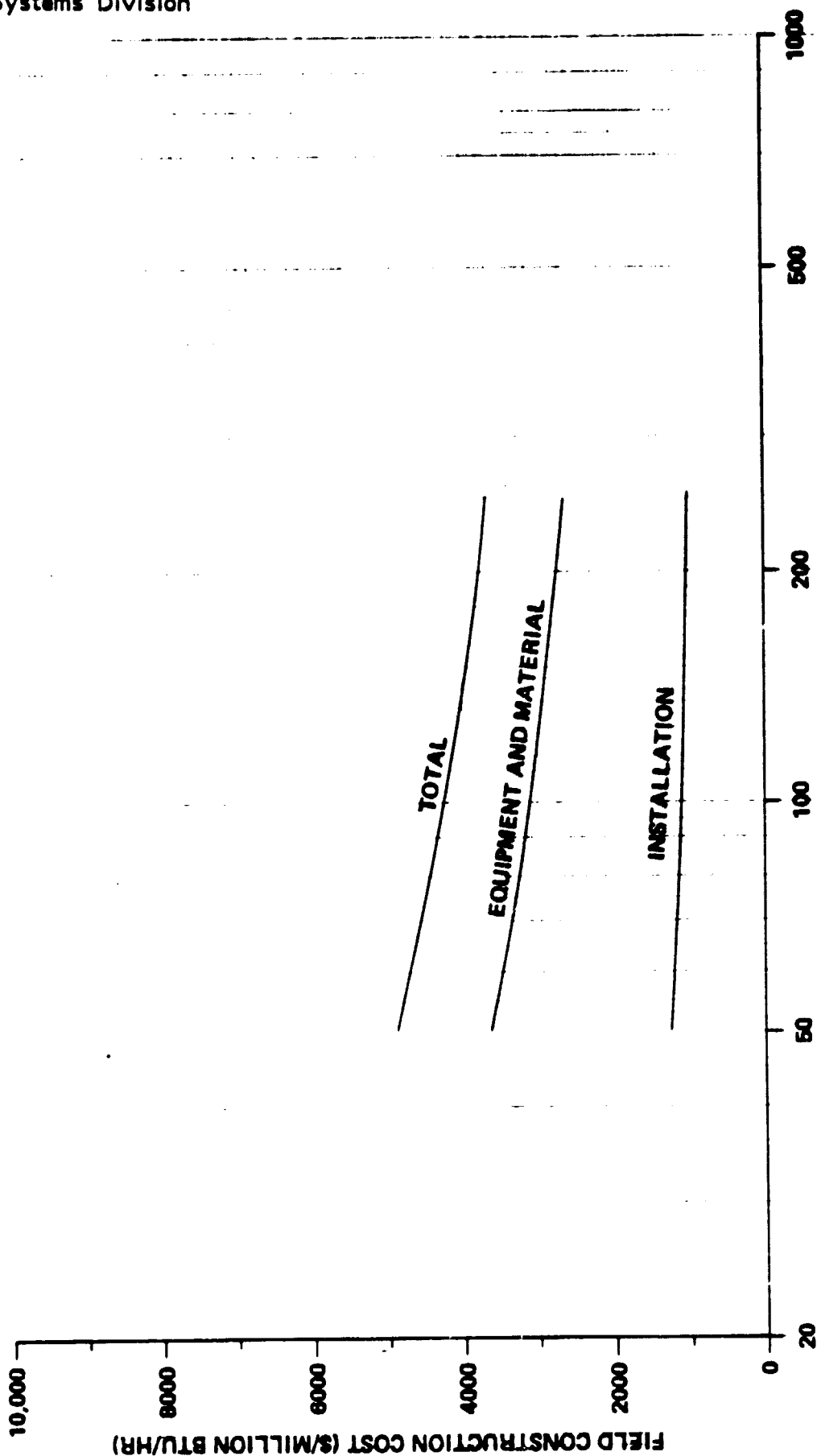


Figure IV-5 VARIATION OF FIELD CONSTRUCTION COST WITH DESIGN THERMAL OUTPUT FOR PETROLEUM RESIDUAL OIL FIRED, 140 F WATER HEATER

TABLE IV-3
PETROLEUM RESIDUAL OIL FIRED, 140F WATER HEATER
FIELD CONSTRUCTION COST
(150 MILLION BTU/HR)

<u>ITEMS</u>	<u>DOLLARS</u>
Equipment	
Furnace (incl. boiler)	221,000
Economizer	22,000
Other Equipment	171,000
Civil/Structural	2,000
Piping/Instrumentation	<u>16,000</u>
Total Equipment and Materials	432,000
Direct Installation Labor (@ \$14/MH)	92,000
Indirects (@ 75% of Direct Labor)	<u>69,000</u>
Total Field Construction Cost (Mid-1978 Dollars)	593,000 =====

CASE 2
PETROLEUM RESIDUAL OIL FIRED, 300F STEAM GENERATOR

The heat source system shown in Figure IV-6 uses a current technology industrial boiler fueled with petroleum residual fuel to produce 50 psig, 300F steam. It is representative of current industrial practice for systems producing 50 to 250 million Btu/hr. The system's design and operating characteristics are as follows.

Characteristics

- Shop assembled, water tube, natural circulation boiler with water-cooled furnace walls for indoor installation
- Pressure reducing valve to achieve required steam conditions
- Forced draft fan with inlet silencer
- Externally mounted windbox with steam atomizing fuel oil burner and duplex fuel oil system
- Externally located finned tube economizer to recover heat from boiler exit gases
- Flue gas damper to maintain natural draft
- Natural draft stack
- Three element feedwater control
- Mechanical linkage type fuel/air ratio control
- Stack gas oxygen content controls excess air
- Staged firing for nitrogen oxides emission control
- Manually operated soot blowers
- Building to enclose all major equipment

Design Point Performance

- Thermal output - 150 million Btu/hr

- Working fluid conditions
Inlet - 15 psig, 250F water
Outlet - 50 psig, 300F steam
- Thermal efficiency - 88% (CTAS ground rule)

Operating Parameters

Table IV-4 gives the flowrate, temperature and pressure for each of the major streams in the system. The stream numbers are identified on the system schematic diagram.

Permissible Range of Operation

The permissible range of operation and thermal efficiency over that range are the same for this system as for the petroleum oil fired, 140F water heater as shown in Figure IV-2.

Effect of Capacity on Efficiency

The variation of design point thermal efficiency with capacity is the same for this system as for the petroleum residual oil fired 140F water heater as shown in Figure IV-3.

Auxiliary Power Requirement

Electric power is required for the forced draft fan and boiler feedwater pump. The power requirement is shown as a function of thermal output in Figure IV-7.

Environmental Intrusion

Table IV-5 gives the stack gas emissions, wastes discharged, and requirements of water and atomizing steam for the heat source system. Data are expressed in pounds of material per million Btu gross energy input to the system (fuel higher heating value). Stack gas emissions were calculated on the basis of fuel specifications defined for this study.

Flexibility and Reliability

This current technology heat source for non-cogeneration applications represents a baseline system to which the advanced technology cogeneration heat sources will be compared. Its characteristics are as follows.

- Fuel Flexibility. The heat source can be modified to fire a wide range of petroleum or coal derived

distillate and residual oils as well as gaseous fuels of varying compositions and heating values. Modifications of the fans, ductwork and burner system would be required. Addition of emission control system for sulfur or particulate removal might also be required for fuels with high sulfur or ash content.

- Transition to Coal or Coal Derived Fuel. Modifications of conventional oil fired units to accept coal firing is not practical due to the differences in combustion and heat release characteristics and fuel handling equipment required. However, coal derived gaseous and liquid fuels can be fired as described in the previous paragraph.
- Operational Flexibility. The unit may be operated from 20% to 110% of design thermal output with only a small change in efficiency.
- Retrofit to Existing Plants. Retrofit potential is good because space requirements are low and the system does not have special operational or safety problems.
- Retrofit of Technology Advancements. The system can be modified to incorporate advances in burner design and combustion air control technology.
- Siting Flexibility. The siting requirements are similar to those typical of an industrial plant. Rail access is required for construction and fuel delivery. Water must be available for boiler feed water makeup. However, the system has no special requirements which will influence siting flexibility.
- Potential Reliability. Reliability has been shown historically to be high. Multiple units can be used to increase reliability without large cost penalties because capital and operating costs are relatively insensitive to unit size.

Space Requirements

The area and volume requirements for the heat source system are expressed as a function of the system thermal output capacity by the following equations,

$$\text{Area (sq ft)} = 630 + 9.4C$$

$$\text{Volume (cu ft)} = 490C$$

where C is equal to the system thermal output capacity in million Btu/hr. The area and volume requirements do not include the exhaust stack.

Maintenance and Overhaul

Scheduled maintenance and overhaul frequencies for the heat source system and the associated planned outages are as follows.

	<u>Maintenance</u>	<u>Overhaul</u>
Interval	12 months	60 months
Planned Outage Required	1 week	4 weeks

Capital and Operating Costs

- Capital Cost. Figure IV-8 shows field construction costs versus thermal output for the heat source system. The costs are broken down into equipment and material cost and installation costs. Installation costs include direct installation labor at \$14.00 per manhour plus 75% of direct labor costs for indirect field costs (distributables). Table IV-6 presents the cost breakdown for a system designed for 150 million Btu/hr thermal output capacity.
- Operating and Maintenance. Annual operating and maintenance costs for the system exclusive of fuel costs are estimated at \$175 per million Btu/hr design thermal output capacity of the heat source.

Construction and Installation Period

A period of approximately two months would be required for construction and installation of the heat source system for the range of sizes considered.

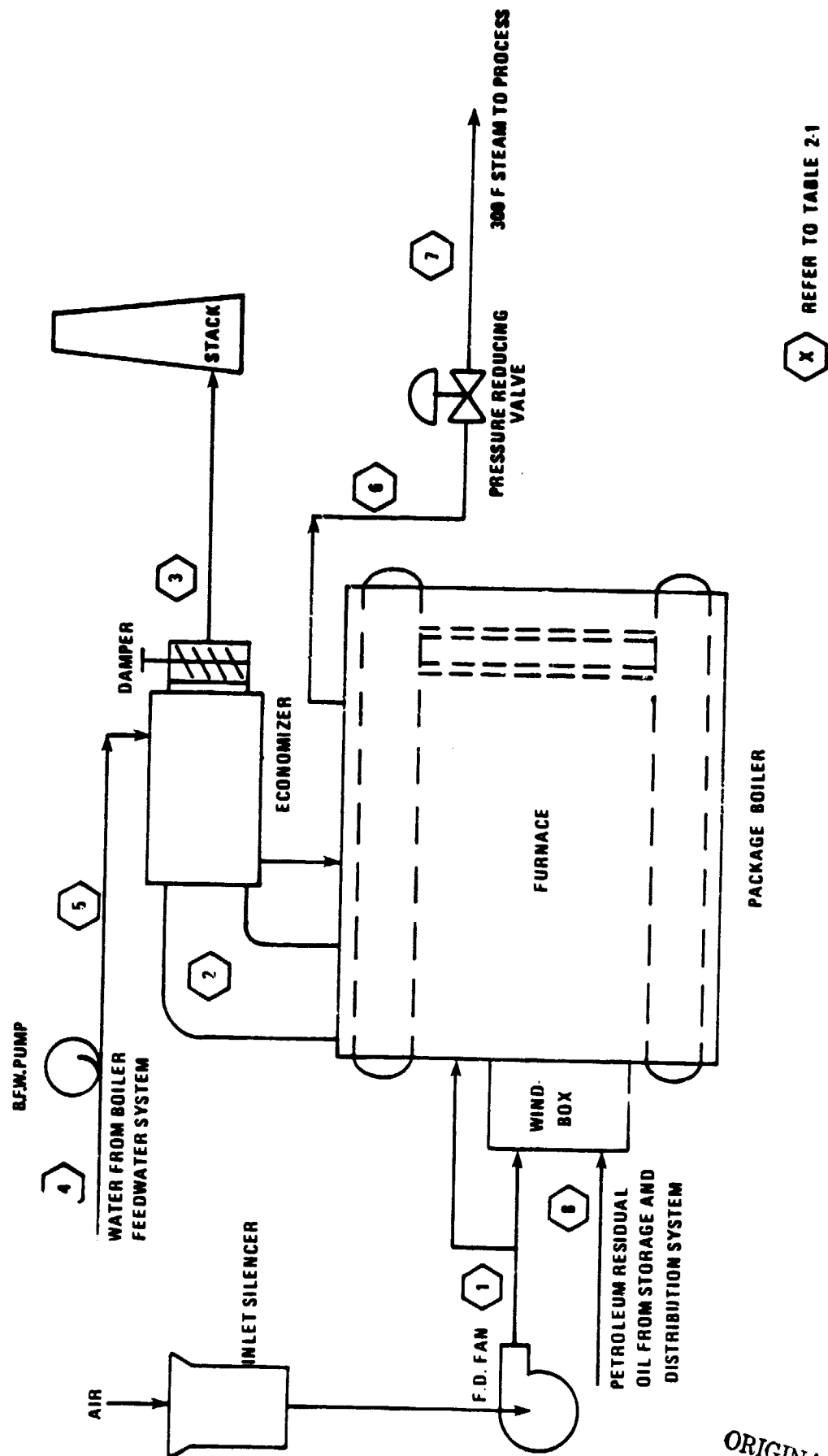


Figure IV-6 PETROLEUM RESIDUAL OIL FIRED, 300F STEAM GENERATOR

TABLE IV-4
PETROLEUM RESIDUAL OIL FIRED, 300F STEAM GENERATOR
OPERATING PARAMETERS
(150 MILLION BTU/HR)

<u>Stream Number</u>	<u>Flowrate (lb/hr)</u>	<u>Temperature (F)</u>	<u>Pressure (psia)</u>
1	146,800*	59	15.6
2	156,000	400	14.8
3	156,000	300	14.7
4	157,600	250	30.0
5	157,600	275	82.0
6	156,000	302	69.0
7	156,000	300	65.0
8	9,200	120	70.0

*15% Excess Combustion Air

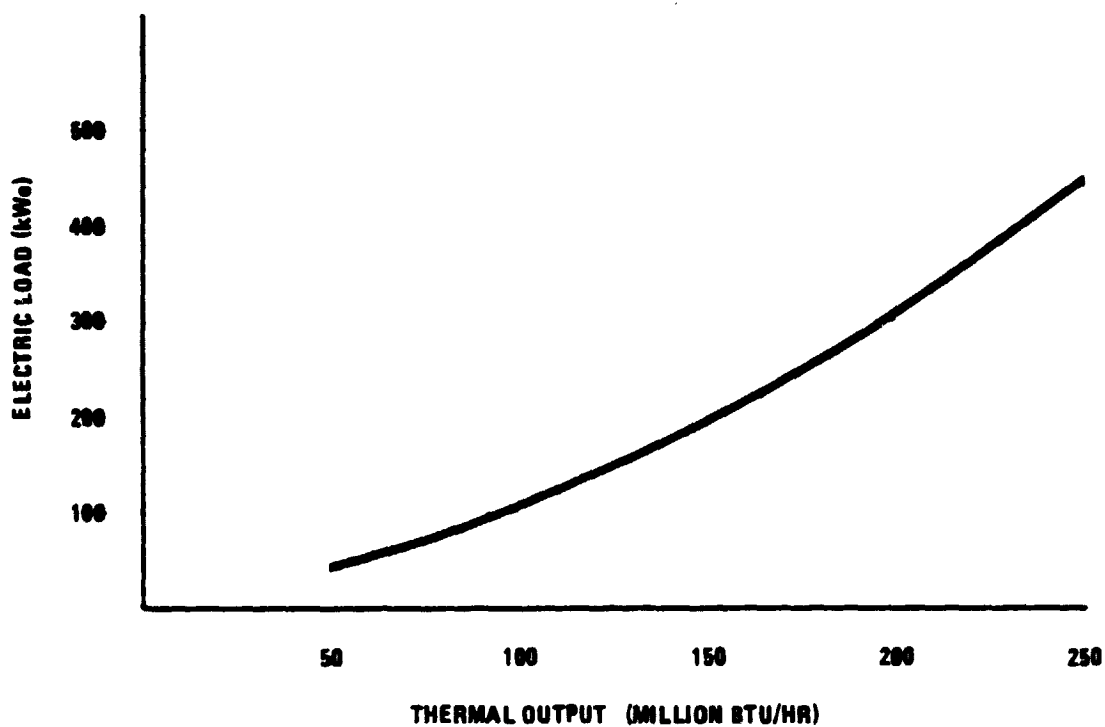


Figure IV-7 VARIATION OF AUXILIARY POWER REQUIRED WITH THERMAL OUTPUT
FOR THE PETROLEUM RESIDUAL OIL FIRED, 300 F STEAM GENERATOR

TABLE IV-5
PETROLEUM RESIDUAL OIL FIRED, 300F STEAM GENERATOR
ENVIRONMENTAL INTRUSION

<u>Stack Gas Emissions</u>	<u>Predicted Rate (lb/million Btu)</u>
Sulfur Dioxide	0.76
Nitrogen Oxides	0.5
Hydrocarbons	0.02
Carbon Monoxide	0.027
Particulates	0.016
<u>Wastes Discharged</u>	
Water (Blowdown)	9.3
Dry Solids	0
Wet Solids	0
<u>Water Required</u>	
(Exclusive of Boiler Feed Water)	0
<u>Steam Required (50 psig, 300F Condition)</u>	
Fuel Atomizing	17.6

COST IN MID-1978 DOLLARS

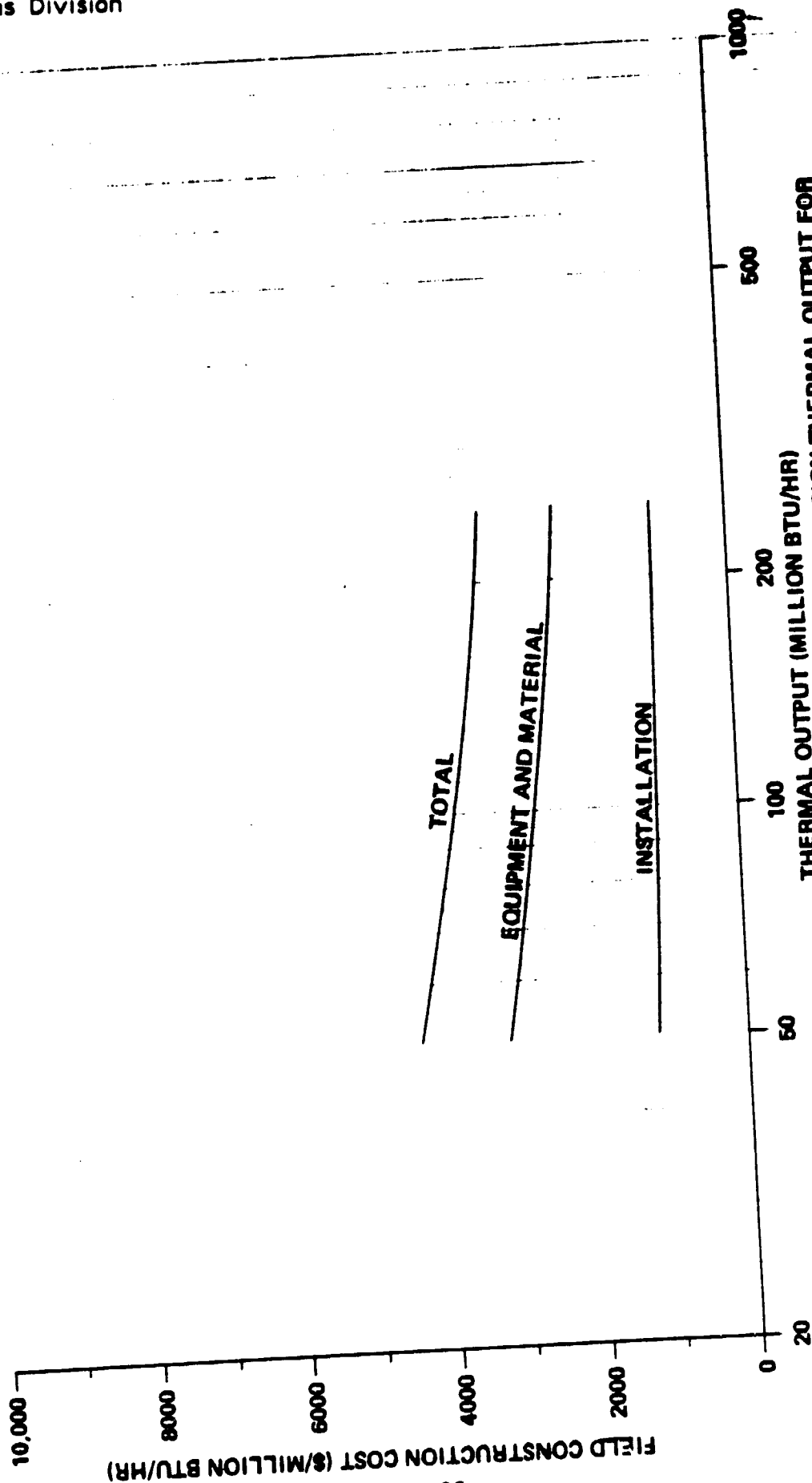


Figure IV-8 VARIATION OF FIELD CONSTRUCTION COST WITH DESIGN THERMAL OUTPUT FOR PETROLEUM RESIDUAL OIL FIRED, 300 F STEAM GENERATOR

TABLE IV-6

PETROLEUM RESIDUAL OIL FIRED, 300F STEAM GENERATOR

FIELD CONSTRUCTION COST

(150 MILLION BTU/HR)

<u>ITEMS</u>	<u>DOLLARS</u>
Equipment	
Furnace (incl. boiler)	222,000
Economizer	22,000
Other Equipment	117,000
 Civil/Structural	 2,000
Piping/Instrumentation	<u>16,000</u>
Total Equipment and Materials	379,000
 Direct Installation Labor (@ \$14/MH)	 89,000
Indirects (@ 75% of Direct Labor)	<u>67,000</u>
 Total Field Construction Cost (Mid-1978 Dollars)	 535,000 =====

CASE 3
PETROLEUM RESIDUAL OIL FIRED, 500F STEAM GENERATOR

The heat source system shown in Figure IV-9 uses a current technology industrial boiler fueled with petroleum residual fuel to produce 600 psig, 500F steam. It is representative of current industrial practice for systems producing 50 to 250 million Btu/hr. The system's design and operating characteristics are as follows.

Characteristics

- Shop assembled, water tube, natural circulation boiler with water-cooled furnace walls for indoor installation
- Forced draft fan with inlet silencer
- Externally located atomizing spray type desuperheater
- Externally mounted windbox with steam atomizing fuel oil burner and duplex fuel oil system
- Externally located finned tube economizer to recover heat from boiler exit gases
- Flue gas damper to maintain natural draft
- Natural draft stack
- Three element feedwater control
- Mechanical linkage type fuel/air ratio control
- Stack gas oxygen content controls excess air
- Staged firing for nitrogen oxides emission control
- Manually operated soot blowers
- Building to enclose all major equipment

Design Point Performance

- Thermal output - 150 million Btu/hr
- Working fluid conditions
 - Inlet - 15 psig, 250F water
 - Outlet - 600 psig, 500F steam
- Thermal efficiency - 88% (CTAS ground rule)

Operating Parameters

Table IV-7 gives the flowrate, temperature and pressure for each of the major streams in the system. The stream numbers are identified on the system schematic diagram.

Permissible Range of Operation

The permissible range of operation and thermal efficiency over that range are the same for this system as for the petroleum oil fired, 140F water heater as shown in Figure IV-2.

Effect of Capacity on Efficiency

The variation of design point thermal efficiency with capacity is the same for this system as for the petroleum residual oil fired 140F water heater as shown in Figure IV-3.

Auxiliary Power Requirement

Electric power is required for the forced draft fan and boiler feedwater pump. The power requirement is shown as a function of thermal output in Figure IV-10.

Environmental Intrusion

Table IV-8 gives the stack gas emissions, wastes discharged, and requirements of water and atomizing steam for the heat source system. Data are expressed in pounds of material per million Btu gross energy input to the system (fuel higher heating value). Stack gas emissions were calculated on the basis of fuel specifications defined for this study.

Flexibility and Reliability

This current technology heat source for non-cogeneration applications represents a baseline system to which the advanced

technology cogeneration heat sources will be compared. Its characteristics are as follows.

- Fuel Flexibility. The heat source can be modified to fire a wide range of petroleum or coal derived distillate and residual oils as well as gaseous fuels of varying compositions and heating values. Modifications of the fans, ductwork and burner system would be required. Addition of emission control system for sulfur or particulate removal might also be required for fuels with high sulfur or ash content.
- Transition to Coal or Coal Derived Fuel. Modifications of conventional oil fired units to accept coal firing is not practical due to the differences in combustion and heat release characteristics and fuel handling equipment required. However, coal derived gaseous and liquid fuels can be fired as described in the previous paragraph.
- Operational Flexibility. The unit may be operated from 20% to 110% of design thermal output with only a small change in efficiency.
- Retrofit to Existing Plants. Retrofit potential is good because space requirements are low and the system does not have special operational or safety problems.
- Retrofit of Technology Advancements. The system can be modified to incorporate advances in burner design and combustion air control technology.
- Siting Flexibility. The siting requirements are similar to those typical of an industrial plant. Rail access is required for construction and fuel delivery. Water must be available for boiler feed water makeup. However, the system has no special requirements which will influence siting flexibility.
- Potential Reliability. Reliability has been shown historically to be high. Multiple units can be used to increase reliability without large cost penalties because capital and operating costs are relatively insensitive to unit size.

Space Requirements

The area and volume requirements for the heat source system are expressed as a function of the system thermal output capacity by the following equations,

$$\text{Area (sq ft)} = 750 + 9.9C$$

$$\text{Volume (cu ft)} = 530C$$

where C is equal to the system thermal output capacity in million Btu/hr. The area and volume requirements do not include the exhaust stack.

Maintenance and Overhaul

Scheduled maintenance and overhaul frequencies for the heat source system and the associated planned outages are as follows.

	<u>Maintenance</u>	<u>Overhaul</u>
Interval	12 months	60 months
Planned Outage Required	1 week	4 weeks

Capital and Operating Costs

- Capital Cost. Figure IV-11 shows field construction costs versus thermal output for the heat source system. The costs are broken down into equipment and material cost and installation costs. Installation costs include direct installation labor at \$14.00 per manhour plus 75% of direct labor costs for indirect field costs (distributables). Table IV-9 presents the cost breakdown for a system designed for 150 million Btu/hr thermal output capacity.
- Operating and Maintenance. Annual operating and maintenance costs for the system exclusive of fuel costs are estimated at \$175 per million Btu/hr design thermal output capacity of the heat source.

Construction and Installation Period

A period of approximately two months would be required for construction and installation of the heat source system for the range of sizes considered.

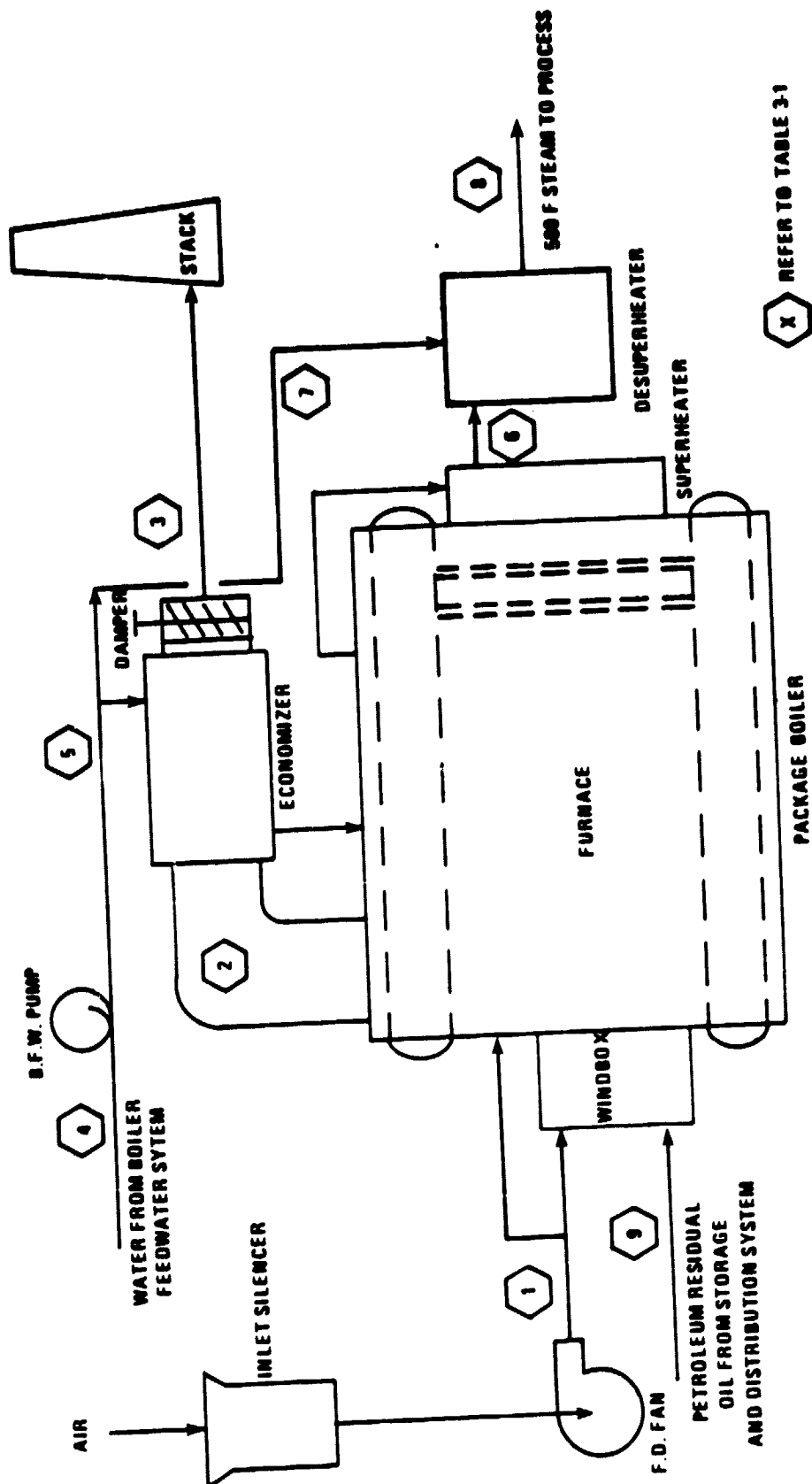


Figure IV-9 PETROLEUM RESIDUAL OIL FIRED, 500F STEAM GENERATOR

TABLE IV-7
PETROLEUM RESIDUAL OIL FIRED, 500F STEAM GENERATOR
OPERATING PARAMETERS
(150 MILLION BTU/HR)

<u>Stream Number</u>	<u>Flowrate (lb/hr)</u>	<u>Temperature (F)</u>	<u>Pressure (psia)</u>
1	146,800*	59	15.6
2	156,000	650	14.8
3	156,000	300	14.7
4	152,300	250	30.0
5	152,300	254	715.0
6	133,000	700	640.0
7	18,000	250	715.0
8	151,000	500	615.0
9	9,200	120	70.0

* 15% Excess Combustion Air

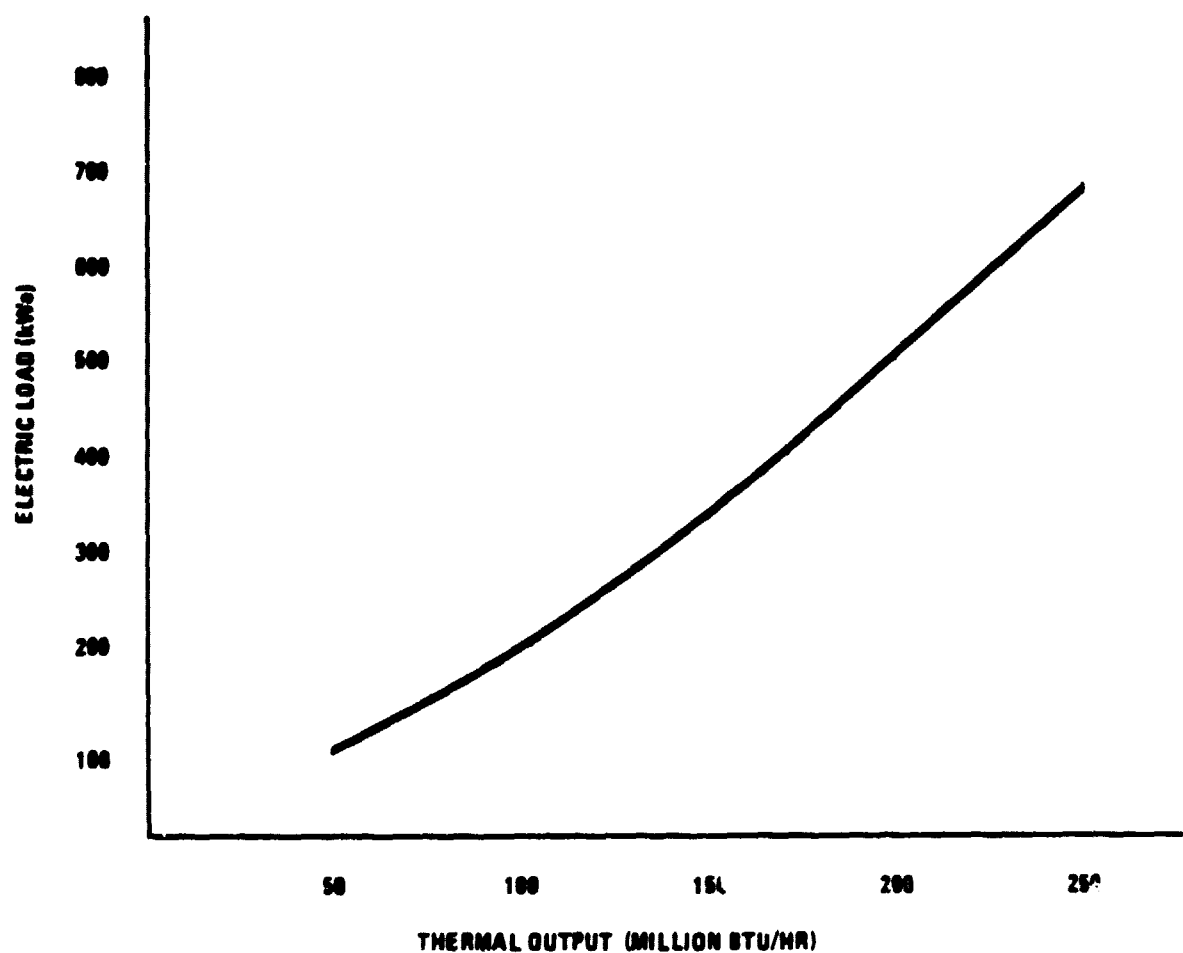


Figure IV-10 VARIATION OF AUXILIARY POWER REQUIRED WITH THERMAL OUTPUT FOR THE PETROLEUM RESIDUAL OIL FIRED, 500 F STEAM GENERATOR

TABLE IV-8

PETROLEUM RESIDUAL OIL FIRED, 500F STEAM GENERATOR
ENVIRONMENTAL INTRUSION

<u>Stack Gas Emissions</u>	<u>Predicted Rate (lb/million Btu)</u>
Sulfur Dioxide	0.76
Nitrogen Oxides	0.5
Hydrocarbons	0.02
Carbon Monoxide	0.027
Particulates	0.016
<u>Wastes Discharged</u>	
Water (Blowdown)	7.9
Dry Solids	0
Wet Solids	0
<u>Water Required</u>	
(Exclusive of Boiler Feed Water)	0
<u>Steam Required (50 psig, 300F Condition)</u>	
Fuel Atomizing	17.6

COST IN MID-1978 DOLLARS

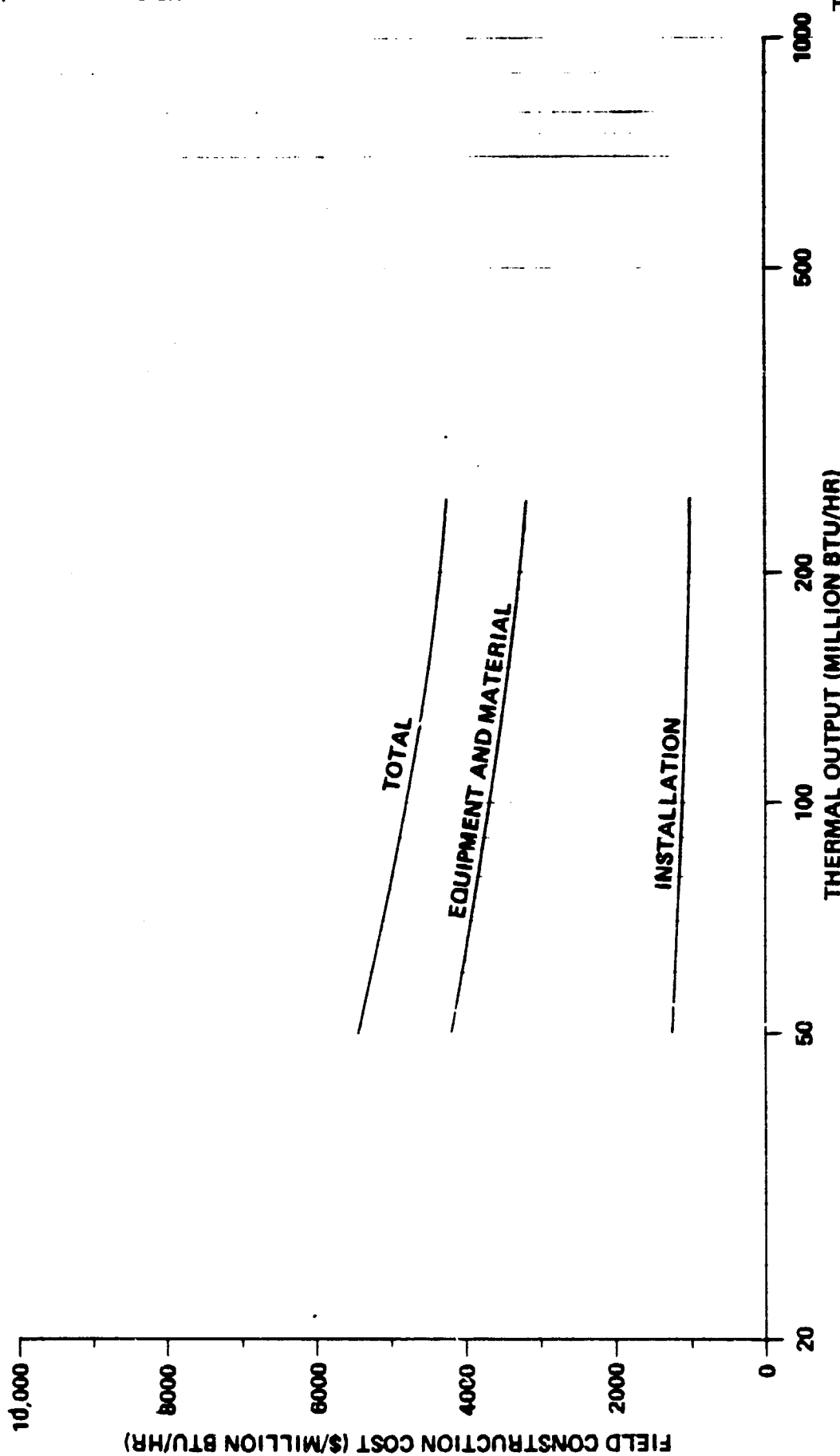


Figure IV-11 VARIATION OF FIELD CONSTRUCTION COST WITH DESIGN THERMAL OUTPUT FOR PETROLEUM RESIDUAL OIL FIRED, 500F STEAM GENERATOR

TABLE IV-9
PETROLEUM RESIDUAL OIL FIRED, 500F STEAM GENERATOR
FIELD CONSTRUCTION COST
(150 MILLION BTU/HR)

<u>ITEMS</u>	<u>DOLLARS</u>
Equipment	
Furnace (incl. boiler)	351,000
Economizer	22,000
Other Equipment	126,000
Civil/Structural	3,000
Piping/Instrumentation	<u>16,000</u>
Total Equipment and Materials	518,000
Direct Installation Labor (@ \$14/MH)	93,000
Indirects (@ 75% of Direct Labor)	<u>70,000</u>
Total Field Construction Cost (Mid-1978 Dollars)	681,000 =====

CASE 4
PETROLEUM RESIDUAL OIL FIRED, 700F STEAM GENERATOR

The heat source system shown in Figure IV-12 uses a current technology industrial boiler fueled with petroleum residual fuel to produce 600 psig, 700F steam. It is representative of current industrial practice for systems producing 50 to 250 million Btu/hr. The system's design and operating characteristics are as follows.

Characteristics

- Shop assembled, water tube, natural circulation boiler with water-cooled furnace walls for indoor installation
- Forced draft fan with inlet silencer
- Externally mounted windbox with steam atomizing fuel oil burner and duplex fuel oil system
- Externally located finned tube economizer to recover heat from boiler exit gases
- Flue gas damper to maintain natural draft
- Natural draft stack
- Three element feedwater control
- Mechanical linkage type fuel/air ratio control
- Stack gas oxygen content controls excess air
- Staged firing for nitrogen oxides emission control
- Manually operated soot blowers
- Building to enclose all major equipment

Design Point Performance

- Thermal output - 150 million Btu/hr
- Working fluid conditions
 - Inlet - 15 psig, 250F water
 - Outlet - 600 psig, 700F steam
- Thermal efficiency - 88% (CTAS ground rule)

Operating Parameters

Table IV-10 gives the flowrate, temperature and pressure for each of the major streams in the system. The stream numbers are identified on the system schematic diagram.

Permissible Range of Operation

The permissible range of operation and thermal efficiency over that range are the same for this system as for the petroleum oil fired, 140F water heater as shown in Figure IV-2.

Effect of Capacity on Efficiency

The variation of design point thermal efficiency with capacity is the same for this system as for the petroleum residual oil fired 140F water heater as shown in Figure IV-3.

Auxiliary Power Requirement

Electric power is required for the forced draft fan and boiler feedwater pump. The power requirement is the same as that shown in Figure IV-10 for the petroleum residual oil fired 500F steam generator.

Environmental Intrusion

Table IV-11 gives the stack gas emissions, wastes discharged, and requirements of water and atomizing steam for the heat source system. Data are expressed in pounds of material per million Btu gross energy input to the system (fuel higher heating value). Stack gas emissions were calculated on the basis of fuel specifications defined for this study.

Flexibility and Reliability

This current technology heat source for non-cogeneration applications represents a baseline system to which the advanced technology cogeneration heat sources will be compared. Its characteristics are as follows.

- Fuel Flexibility. The heat source can be modified to fire a wide range of petroleum or coal derived distillate and residual oils as well as gaseous fuels of varying compositions and heating values. Modifications of the fans, ductwork and burner system would be required. Addition of emission control system for sulfur or particulate removal

might also be required for fuels with high sulfur or ash content.

- Transition to Coal or Coal Derived Fuel. Modifications of conventional oil fired units to accept coal firing is not practical due to the differences in combustion and heat release characteristics and fuel handling equipment required. However, coal derived gaseous and liquid fuels can be fired as described in the previous paragraph.
- Operational Flexibility. The unit may be operated from 20% to 110% of design thermal output with only a small change in efficiency.
- Retrofit to Existing Plants. Retrofit potential is good because space requirements are low and the system does not have special operational or safety problems.
- Retrofit of Technology Advancements. The system can be modified to incorporate advances in burner design and combustion air control technology.
- Siting Flexibility. The siting requirements are similar to those typical of an industrial plant. Rail access is required for construction and fuel delivery. Water must be available for boiler feed water makeup. However, the system has no special requirements which will influence siting flexibility.
- Potential Reliability. Reliability has been shown historically to be high. Multiple units can be used to increase reliability without large cost penalties because capital and operating costs are relatively insensitive to unit size.

Space Requirements

The area and volume requirements for the heat source system are expressed as a function of the system thermal output capacity by the following equations,

$$\text{Area (sq ft)} = 750 + 9.9C$$

$$\text{Volume (cu ft)} = 530C$$

where C is equal to the system thermal output capacity in million Btu/hr. The area and volume requirements do not include the exhaust stack.

Maintenance and Overhaul

Scheduled maintenance and overhaul frequencies for the heat source system and the associated planned outages are as follows.

	<u>Maintenance</u>	<u>Overhaul</u>
Interval	12 months	60 months
Planned Outage Required	1 week	4 weeks

Capital and Operating Costs

- Capital Cost. Figure IV-13 shows field construction costs versus thermal output for the heat source system. The costs are broken down into equipment and material cost and installation costs. Installation costs include direct installation labor at \$14.00 per manhour plus 75% of direct labor costs for indirect field costs (distributables). Table IV-12 presents the cost breakdown for a system designed for 150 million Btu/hr thermal output capacity.
- Operating and Maintenance. Annual operating and maintenance costs for the system exclusive of fuel costs are estimated at \$175 per million Btu/hr design thermal output capacity of the heat source.

Construction and Installation Period

A period of approximately two months would be required for construction and installation of the heat source system for the range of sizes considered.

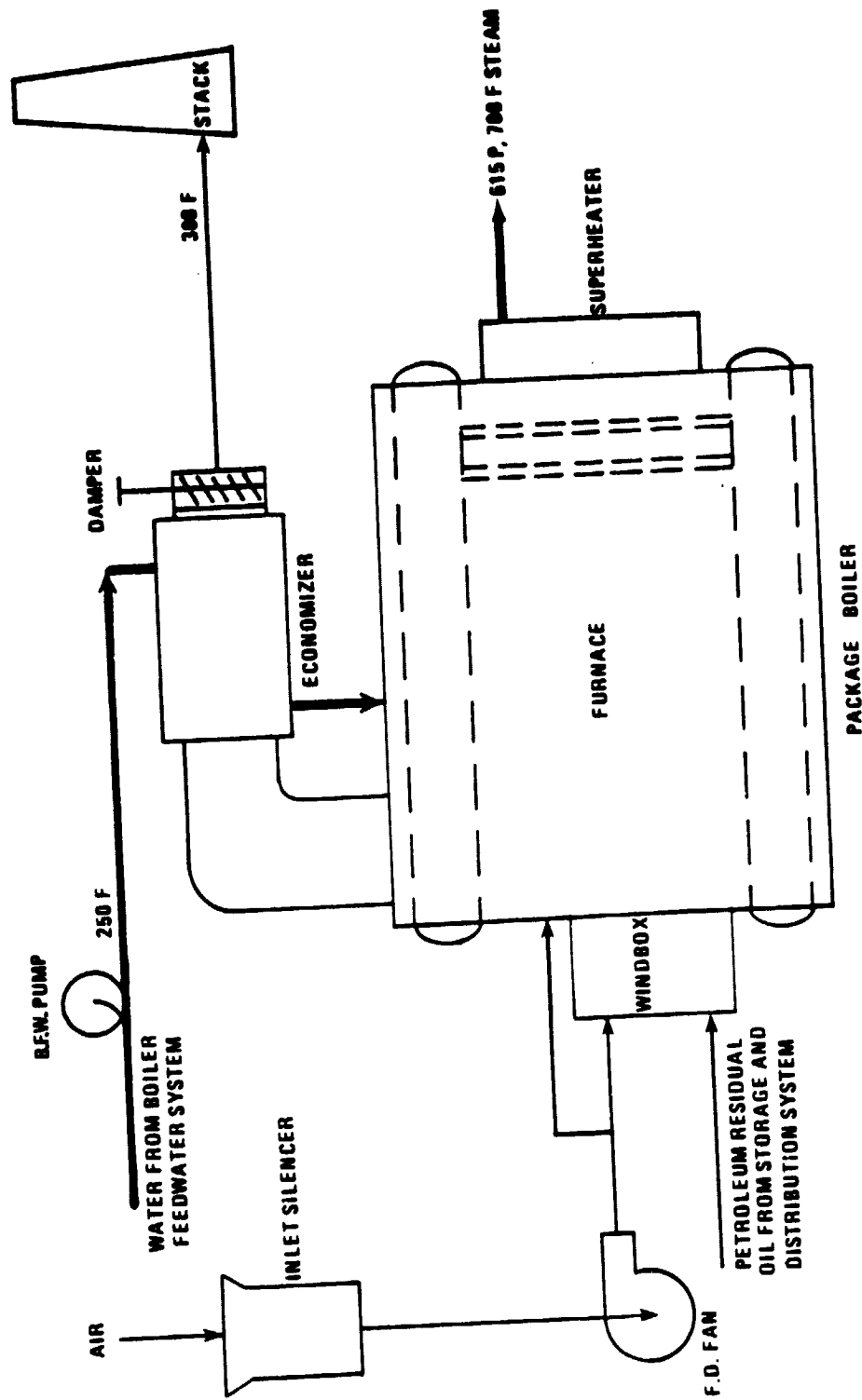


Figure IV-12 PETROLEUM RESIDUAL OIL FIRED, 700F STEAM GENERATOR

TABLE IV-10
PETROLEUM RESIDUAL OIL FIRED, 700F STEAM GENERATOR
OPERATING PARAMETER
(150 MILLION BTU/HR)

<u>Stream Number</u>	<u>Flowrate (lb/hr)</u>	<u>Temperature (F)</u>	<u>Pressure (psia)</u>
1	146,800*	59	15.6
2	156,000	650	14.8
3	156,000	300	14.7
4	134,300	250	30.0
5	134,300	254	690.0
6	133,000	700	615.0
7	9,200	120	70.0

* 15% Excess Combustion Air

TABLE IV-11

PETROLEUM RESIDUAL OIL FIRED, 700F STEAM GENERATOR
ENVIRONMENTAL INTRUSION

<u>Stack Gas Emissions</u>	<u>Predicted Rate (lb/million Btu)</u>
Sulfur Dioxide	0.76
Nitrogen Oxides	0.5
Hydrocarbons	0.02
Carbon Monoxide	0.027
Particulates	0.016
<u>Wastes Discharged</u>	
Water (Blowdown)	7.9
Dry Solids	0
Wet Solids	0
<u>Water Required</u>	
(Exclusive of Boiler Feed Water)	0
<u>Steam Required (50 psig, 300F Condition)</u>	
Fuel Atomizing	17.6

COST IN MID-1978 DOLLARS

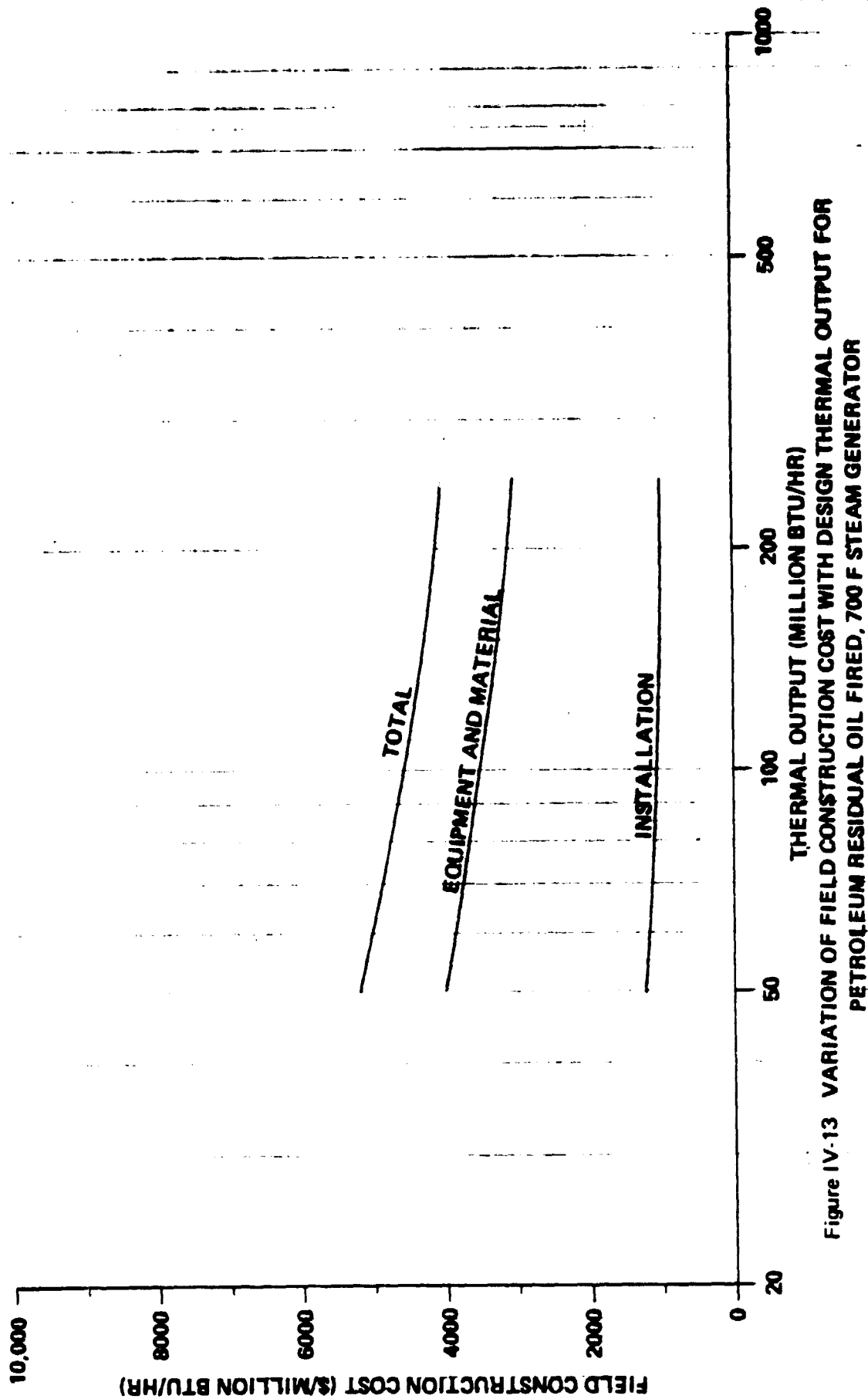


Figure IV-13 VARIATION OF FIELD CONSTRUCTION COST WITH DESIGN THERMAL OUTPUT FOR PETROLEUM RESIDUAL OIL FIRED, 700 F STEAM GENERATOR

TABLE IV-12

PETROLEUM RESIDUAL OIL FIRED, 700F STEAM GENERATOR

FIELD CONSTRUCTION COST

(150 MILLION BTU/HR)

<u>ITEMS</u>	<u>DOLLARS</u>
Equipment	
Furnace (incl. boiler)	327,000
Economizer	22,000
Other Equipment	124,000
 Civil/Structural	 2,000
Piping/Instrumentation	<u>16,000</u>
Total Equipment and Materials	491,000
 Direct Installation Labor (@ \$14/MH)	 89,000
Indirects (@ 75% of Direct Labor)	<u>67,000</u>
 Total Field Construction Cost (Mid-1978 Dollars)	 647,000 =====

CASE 5
PETROLEUM RESIDUAL OIL FIRED, 950F STEAM GENERATOR

The petroleum residual oil fired, 950F steam generator shown in Figure IV-14 is a current technology high pressure industrial boiler system including an economizer and air heater for heat recovery. The system incorporates a shop assembled package boiler for thermal outputs ranging from 50 to 250 million Btu/hr and a field assembled unit for capacities greater than 250 million Btu/hr. The design and operating characteristics of the system are as follows.

Characteristics

The following characteristics describe the system which includes a package boiler (thermal output less than 250 million Btu/hr).

- Shop assembled, water tube, natural circulation boiler with water-cooled furnace walls
- Radiation type superheater with no exit temperature control
- Forced draft fan with inlet silencer
- Externally mounted windbox with steam atomizing fuel oil burner and duplex fuel oil system
- Externally located finned tube economizer to recover heat from boiler exit gases
- Externally located tubular type air heater
- Natural draft stack
- Three element feedwater control
- Mechanical linkage type fuel/air ratio control
- Stack gas oxygen content controls excess air
- Manually operated soot blowers
- Staged firing for nitrogen oxides emission control
- Building encloses all major equipment

The characteristics for the system including a field assembled boiler (greater than 250 million Btu/hr output) are as follows:

- Field assembled, water tube, natural circulation boiler with water-cooled furnace walls
- Attenuation type two stage superheater for exit steam temperature control
- Forced draft fan with inlet silencer
- Induced draft fan for balanced draft operation with stack
- Integrated windbox with steam atomizing fuel oil burner
- Externally located finned tube economizer to recover heat from boiler exit gases
- Externally located tubular type air heater
- Three element feedwater control
- Metering type fuel/air ratio control
- Stack gas oxygen content controls excess air
- Electrically operated steam soot blowers
- Staged firing for nitrogen oxides emission control

Design Point Performance

- Thermal output - 500 million Btu/hr
- Working fluid conditions
 - Inlet - 15 psig, 250F water
 - Outlet - 1200 psig, 950F steam
- Thermal efficiency - 88% (CTAS ground rule)

Operating Parameters

Table IV-13 gives the flowrate, temperature and pressure for each of the major streams in the system. The stream numbers are identified in the system schematic diagram.

Permissible Range of Operation

Figure IV-15 shows the variation in thermal efficiency over the permissible range of operation.

Effect of Capacity on Efficiency

Design point efficiency varies only slightly over the range of thermal output considered. The variation which is shown in Figure IV-16 is due to change in the radiation losses from the boiler.

Auxiliary Power Requirement

Electric power is required for the fans and boiler feedwater pump. The power requirement is 3.0 kWe per million Btu/hr.

Environmental Intrusion

Table IV-14 gives the stack gas emissions, wastes discharged, and requirements of water and atomizing steam for the heat source system. Data are expressed in pounds of material per million Btu gross energy input to the system (fuel higher heating value). Stack gas emissions were calculated on the basis of fuel specifications defined for this study.

Flexibility and Reliability

This current technology heat source for cogeneration applications represents a baseline system to which the advanced technology cogeneration heat sources will be compared. Its characteristics are as follows.

- Fuel Flexibility. The heat source can be modified to fire a wide range of petroleum or coal derived distillate and residual oils as well as gaseous fuels of varying compositions and heating values. Modifications of the fans, ductwork and burner system would be required. Addition of emission control system for sulfur or particulate removal might also be required for fuels with high sulfur or ash content.
- Transition to Coal or Coal Derived Fuel. Modifications of conventional oil fired units to accept coal firing is not practical due to the differences in combustion and heat release characteristics and fuel handling equipment required. However, coal derived gaseous and liquid

fuels can be fired as described in the previous paragraph.

- Operational Flexibility. The unit may be operated from 20% to 110% of design thermal output with only a small change in efficiency.
- Retrofit to Existing Plants. Retrofit potential is good because space requirements are low and the system does not have special operational or safety problems.
- Retrofit of Technology Advancements. The system can be modified to incorporate advances in burner design and combustion air control technology.
- Siting Flexibility. The siting requirements are similar to those typical of an industrial plant. Rail access is required for construction and fuel delivery. Water must be available for boiler feed water makeup. However, the system has no special requirements which will influence siting flexibility.
- Potential Reliability. Reliability has been shown historically to be high. Multiple units can be used to increase reliability without large cost penalties because capital and operating costs are relatively insensitive to unit size.

Space Requirements

The area and volume requirements for the heat source system are expressed as a function of the system thermal output capacity by the following equations,

$$\begin{array}{lll} \text{Area (sq ft)} & = 750 + 9.9C & (50 \leq C \leq 250) \\ & = 13C & (C > 250) \end{array}$$

$$\begin{array}{lll} \text{Volume (cu ft)} & = 530C & (50 \leq C \leq 250) \\ & = 850C & (C > 250) \end{array}$$

where C is equal to the system thermal output capacity in million Btu/hr. The area and volume requirements do not include the exhaust stack.

Maintenance and Overhaul

Scheduled maintenance and overhaul frequencies for the heat source system and the associated planned outages are as follows.

	<u>Maintenance</u>	<u>Overhaul</u>
Interval	12 months	60 months
Planned Outage Required		
- Thermal Output		
≤ 250 million Btu/hr	1 week	4 weeks
> 250 million Btu/hr	2 weeks	8 weeks

Capital and Operating Costs

- Capital Cost. Figure IV-17 shows field construction costs versus thermal output for the heat source system. The costs are broken down into equipment and material cost and installation costs. Installation costs include direct installation labor at \$14.00 per manhour plus 75% of direct labor costs for indirect field costs (distributables). Table IV-15 presents the cost breakdown for a system designed for 500 million Btu/hr thermal output capacity and Table IV-16 presents the cost breakdown for a system designed for 100 million Btu/hr thermal output capacity.
- Operating and Maintenance. Annual operating and maintenance costs for the system exclusive of fuel costs are estimated at \$175 per million Btu/hr design thermal output capacity of the heat source.

Construction and Installation Period

The construction and installation period required for the heat source is expressed as a function of the system thermal output capacity by the following equations:

$$M = 2 \quad (50 \leq C \leq 250)$$

$$M = \frac{C}{200} \times 21 \quad (C > 250)$$

where M is equal to construction and installation period in months and C is equal to system thermal output capacity in million Btu/hr.

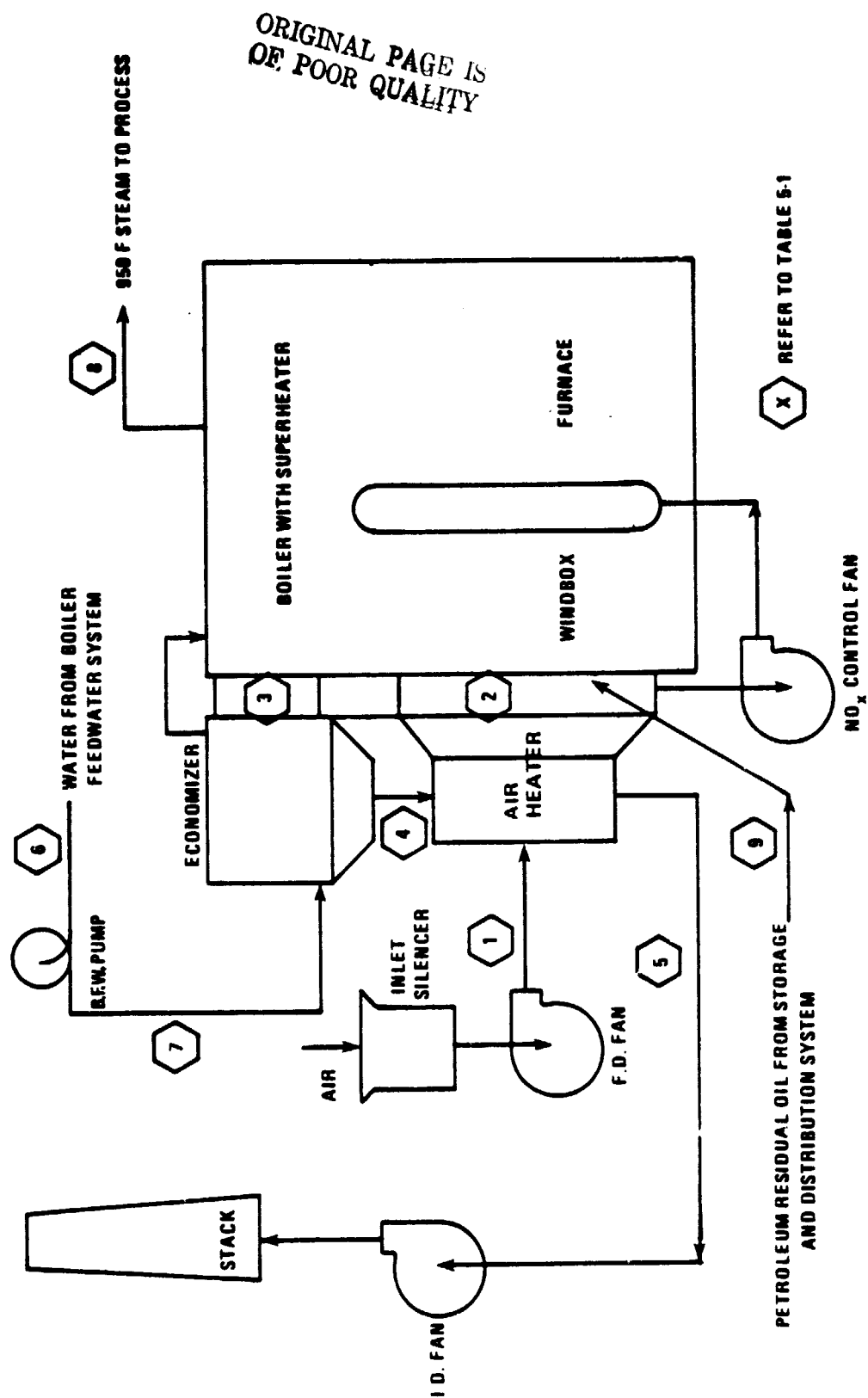


Figure IV-14 PETROLEUM RESIDUAL OIL FIRED, 950F STEAM GENERATOR

TABLE IV-13
PETROLEUM RESIDUAL OIL FIRED, 950F STEAM GENERATOR
OPERATING PARAMETERS
(500 MILLION BTU/HR)

<u>Stream Number</u>	<u>Flowrate (lb/hr)</u>	<u>Temperature (F)</u>	<u>Pressure (psia)</u>
1	488,300*	59	15.1
2	488,000	270	15.0
3	519,000	1000	14.7
4	519,000	500	14.5
5	519,000	300	14.3
6	403,000	250	30.0
7	403,000	255	1365.0
8	399,000	950	1215.0
9	30,700	120	70.0

* 15% Excess Combustion Air

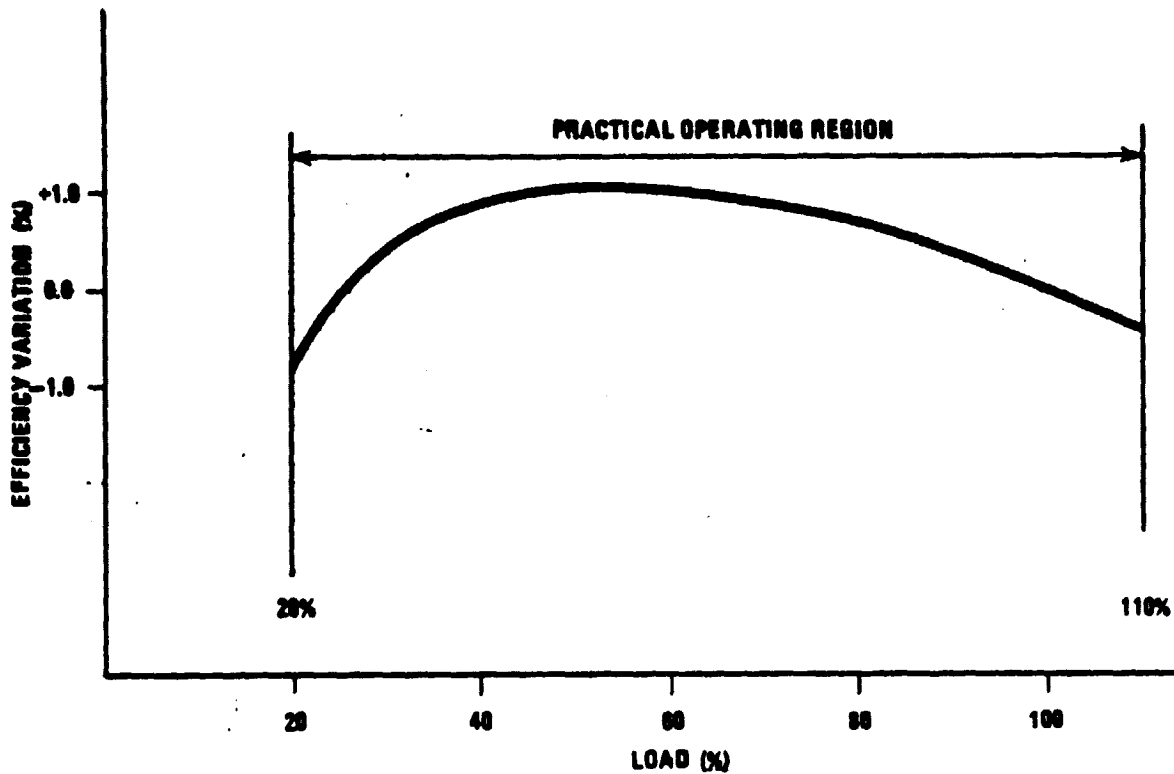


Figure IV-15 VARIATION OF THERMAL EFFICIENCY WITH PERCENT LOAD FOR THE PETROLEUM RESIDUAL OIL FIRED, 950 F STEAM GENERATOR

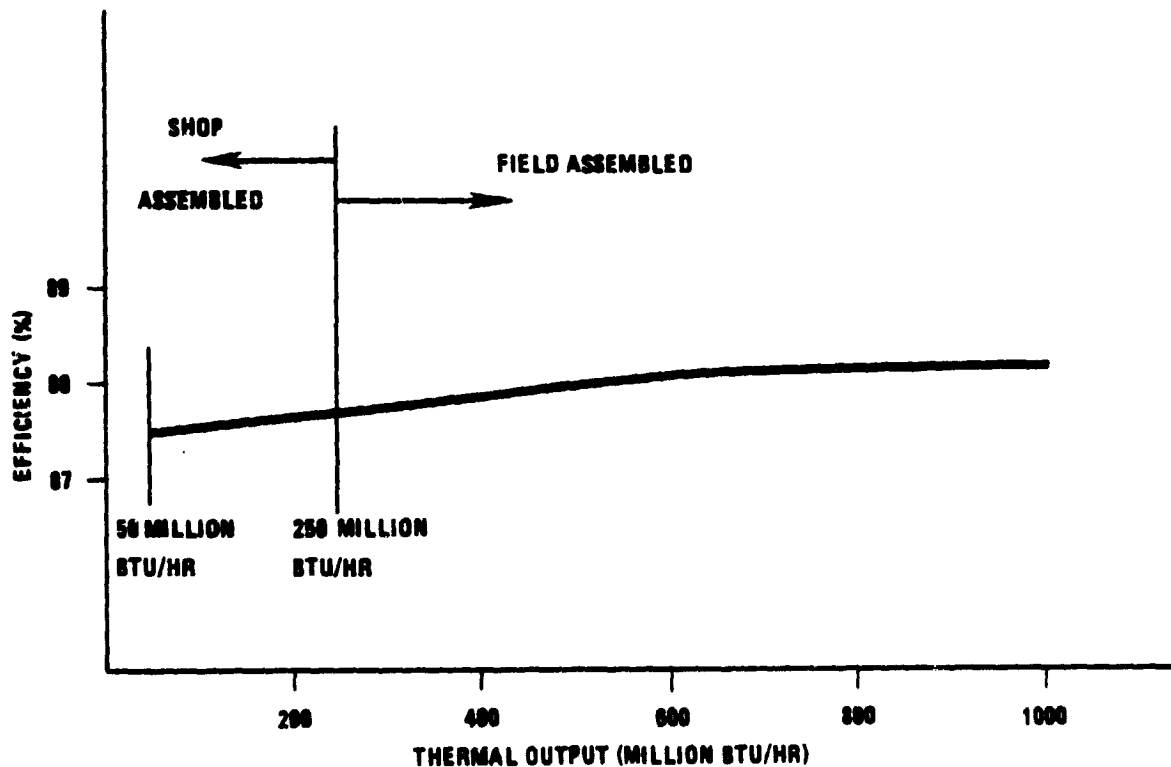


Figure IV-16 VARIATION OF DESIGN POINT EFFICIENCY WITH DESIGN POINT OUTPUT FOR THE PETROLEUM RESIDUAL OIL FIRED, 950 F STEAM GENERATOR

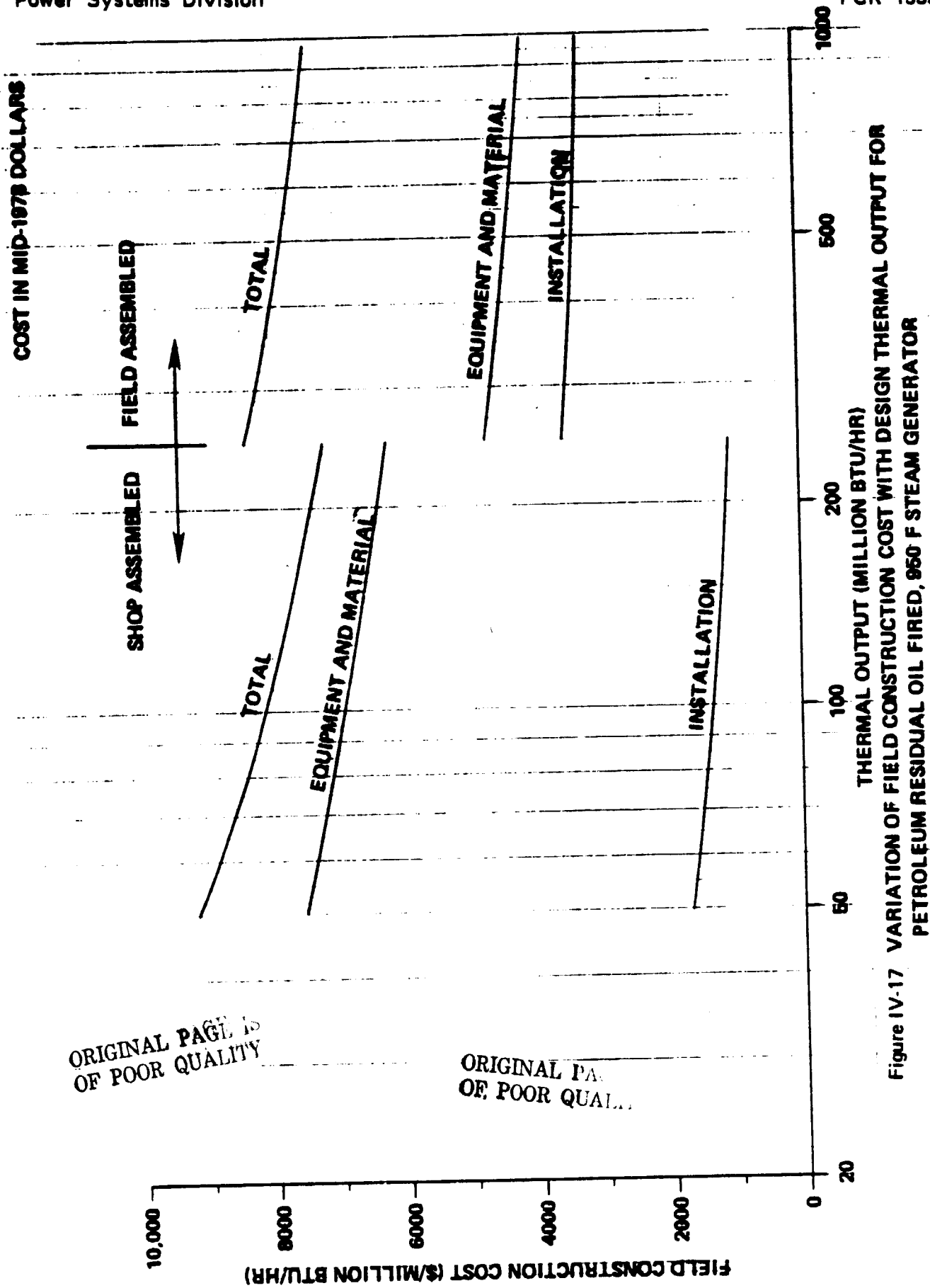


Figure IV-17 VARIATION OF FIELD CONSTRUCTION COST WITH DESIGN THERMAL OUTPUT FOR PETROLEUM RESIDUAL OIL FIRED, 950 F STEAM GENERATOR

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TABLE IV-14

PETROLEUM RESIDUAL OIL FIRED, 950F STEAM GENERATOR
ENVIRONMENTAL INTRUSION

<u>Stack Gas Emissions</u>	<u>Predicted Rate (lb/million Btu)</u>
Sulfur Dioxide	0.76
Nitrogen Oxides	0.5
Hydrocarbons	0.02
Carbon Monoxide	0.027
Particulates	0.016
 <u>Wastes Discharged</u>	
Water (Blowdown)	7.1
Dry Solids	0
Wet Solids	0
 <u>Water Required</u>	
(Exclusive of Boiler Feed Water)	0
 <u>Steam Required (50 psig, 300F Condition)</u>	
Fuel Atomizing	17.6

TABLE IV-15

PETROLEUM RESIDUAL OIL FIRED, 950F STEAM GENERATOR

FIELD CONSTRUCTION COST

(500 MILLION BTU/HR)

<u>ITEMS</u>	<u>DOLLARS</u>
Equipment	
Furnace, Field Erected (incl. boiler economizer and air heater)	1,750,000
Other Equipment	190,000
Civil/Structural	23,000
Piping/Instrumentation	<u>223,000</u>
Total Equipment and Materials	2,186,000
Direct Installation Labor (@ \$14/MH)	971,000
Indirects (@ 75% of Direct Labor)	<u>728,000</u>
Total Field Construction Cost (Mid-1978 Dollars)	3,885,000 =====

TABLE IV-16
PETROLEUM RESIDUAL OIL FIRED, 950F STEAM GENERATOR
FIELD CONSTRUCTION COST
(100 MILLION BTU/HR)

<u>ITEMS</u>	<u>DOLLARS</u>
Equipment	
Furnace, Shop Assembled (incl. boiler, economizer and air heater)	533,000
Other Equipment	108,000
 Civil/Structural	 10,000
Piping/Instrumentation	<u>39,000</u>
Total Equipment and Materials	690,000
 Direct Installation Labor (@ \$14/MH)	 74,000
Indirects (@ 75% of Direct Labor)	<u>56,000</u>
 Total Field Construction Cost (Mid-1978 Dollars)	 820,000 =====

CASE 6
COAL DERIVED RESIDUAL OIL FIRED, 1050F STEAM GENERATOR

The coal derived residual oil fired steam generator, shown in Figure IV-18, is an advanced technology industrial boiler system which produces steam at 1800 psig, 1050F; slightly higher temperature and pressure than available from current technology units. The boiler varies from current design practice only in its materials of construction. The system incorporates a shop assembled package boiler for thermal outputs ranging from 50 to 250 million Btu/hr and a field assembled unit for capacities greater than 250 million Btu/hr.

Characteristics

The following characteristics describe the system which includes a package boiler (thermal output less than 250 million Btu/hr).

- Shop assembled, water tube, natural circulation boiler with water-cooled furnace walls
- Radiation type superheater with no exit steam temperature control
- Forced draft fan with inlet silencer
- Externally mounted windbox with steam atomizing fuel oil burner and duplex fuel oil system
- Externally located finned tube economizer to recover heat from boiler exit gases
- Externally located tubular type air heater
- Natural draft stack
- Three element feedwater control
- Mechanical linkage type fuel/air ratio control
- Stack gas oxygen content controls excess air
- Manually operated soot blowers
- Staged firing for nitrogen oxides emission control
- Building encloses all major equipment
- A flue gas particulate removal system (ESP) required because of high ash content of fuel

The characteristics for the system which includes a field assembled boiler (greater than 250 million Btu/hr output) are as follows:

- Field assembled, water tube, natural circulation boiler with water-cooled furnace walls
- Attenuation type, two stage superheater for steam temperature control
- Forced draft fan with inlet silencer
- Induced draft fan for balanced draft operation with stack
- Integrated windbox with steam atomizing fuel oil burner
- Externally located finned tube economizer to recover heat from boiler exit gases
- Externally located tubular type air heater
- Three element feedwater control
- Metering type fuel/air ratio control
- Stack gas oxygen content controls excess air
- Electrically operated steam soot blowers
- Staged firing for nitrogen oxides emission control
- Flue gas particulate removal system (ESP) required because of high ash content of fuel

Design Point Performance

- Thermal output - 500 million Btu/hr
- Working fluid conditions
 - Inlet - 15 psig, 250F water
 - Outlet - 1800 psig, 1050F steam
- Thermal efficiency - 88.5%

Operating Parameters

Table IV-17 gives the flowrate, temperature and pressure for each of the major streams in the system. The stream numbers are identified in the system schematic diagram.

Permissible Range of Operation

Figure IV-19 shows the variation in thermal efficiency over the permissible range of operation.

Effect of Capacity on Efficiency

Design point efficiency varies only slightly over the range of thermal output considered. The variation which is shown in Figure IV-20 is due to change in the radiation losses from the boiler.

Auxiliary Power Requirement

Electric power is required for the fans and boiler feedwater pump. The power requirement is 4.1 kWe per million Btu/hr.

Environmental Intrusion

Table IV-18 gives the stack gas emissions, wastes discharged, and requirements of water and atomizing steam for the heat source system. Data are expressed in pounds of material per million Btu gross energy input to the system (fuel higher heating value). Stack gas emissions for the heat source including a particulate removal system were calculated on the basis of fuel specifications defined for this study.

Flexibility and Reliability

This advanced technology heat source has flexibility and reliability characteristics similar to a current technology oil fired unit. Its characteristics are as follows.

- Fuel Flexibility. The heat source can be modified to fire a wide range of petroleum or coal derived distillate and residual oils as well as gaseous fuels of varying compositions and heating values. Modifications of the fans, ductwork and burner system would be required. Addition of an emission control system for sulfur removal might also be required for fuels with high sulfur content.
- Transition to Coal or Other Coal Derived Fuel. Modifications of conventional oil fired units to accept coal firing is not practical due to the differences in combustion and heat release characteristics and fuel handling equipment required. However, coal derived gaseous fuels can be fired as described in the previous paragraph.

- Operational Flexibility. The unit may be operated from 20% to 110% of design thermal output with only a small change in efficiency.
- Retrofit to Existing Plants. Retrofit potential is good because space requirements are low and the system does not have special operational or safety problems.
- Retrofit of Technology Advancements. The system can be modified to incorporate advances in burner design and combustion air control technology.
- Siting Flexibility. The siting requirements are similar to those typical of an industrial plant. Rail access is required for construction and fuel delivery. Water must be available for boiler feed water makeup. However, the system has no special requirements which will influence siting flexibility.
- Potential Reliability. Reliability can be assumed to be high because the system represents only a small deviation from current technology units of proven reliability. Multiple units can be used to increase reliability without large cost penalties because capital and operating costs are relatively insensitive to unit size.

Space Requirements

The area and volume requirements for the heat source system are expressed as a function of the system thermal output capacity by the following equations,

$$\begin{array}{lll} \text{Area (sq ft)} & = 750C + 9.9C & (50 \leq C \leq 250) \\ & = 13C & (C > 250) \end{array}$$

$$\begin{array}{lll} \text{Volume (cu ft)} & = 530C & (50 \leq C \leq 250) \\ & = 850C & (C > 250) \end{array}$$

where C is equal to the system thermal output capacity in million Btu/hr. The area and volume requirements do not include the exhaust stack.

Maintenance and Overhaul

Scheduled maintenance and overhaul frequencies for the heat source system and the associated planned outages are as follows.

	<u>Maintenance</u>	<u>Overhaul</u>
Interval	12 months	60 months
Planned Outage Required		
- Thermal Output		
< 250 million Btu/hr	1 week	4 weeks
> 250 million Btu/hr	2 weeks	8 weeks

Capital and Operating Costs

- Capital Cost. Figure IV-21 shows field construction costs versus thermal output for the heat source system. The costs are broken down into equipment and material cost and installation costs. Installation costs include direct installation labor at \$14.00 per manhour plus 75% of direct labor costs for indirect field costs (distributables). Table IV-19 presents the cost breakdown for a system designed for 500 million Btu/hr thermal output capacity and Table IV-20 presents the cost breakdown for a system designed for 100 million Btu/hr thermal output capacity.
- Operating and Maintenance. Annual operating and maintenance costs for the system exclusive of fuel costs are estimated at \$175 per million Btu/hr design thermal output capacity of the heat source.

Construction and Installation Period

The construction and installation period required for the heat source is expressed as a function of the system thermal output capacity by the following equations:

$$M = 2 \quad (50 \leq C \leq 250)$$

$$M = \frac{C}{200} \times 21 \quad (C > 250)$$

where M is equal to construction and installation period in months and C is equal to system thermal output capacity in million Btu/hr.

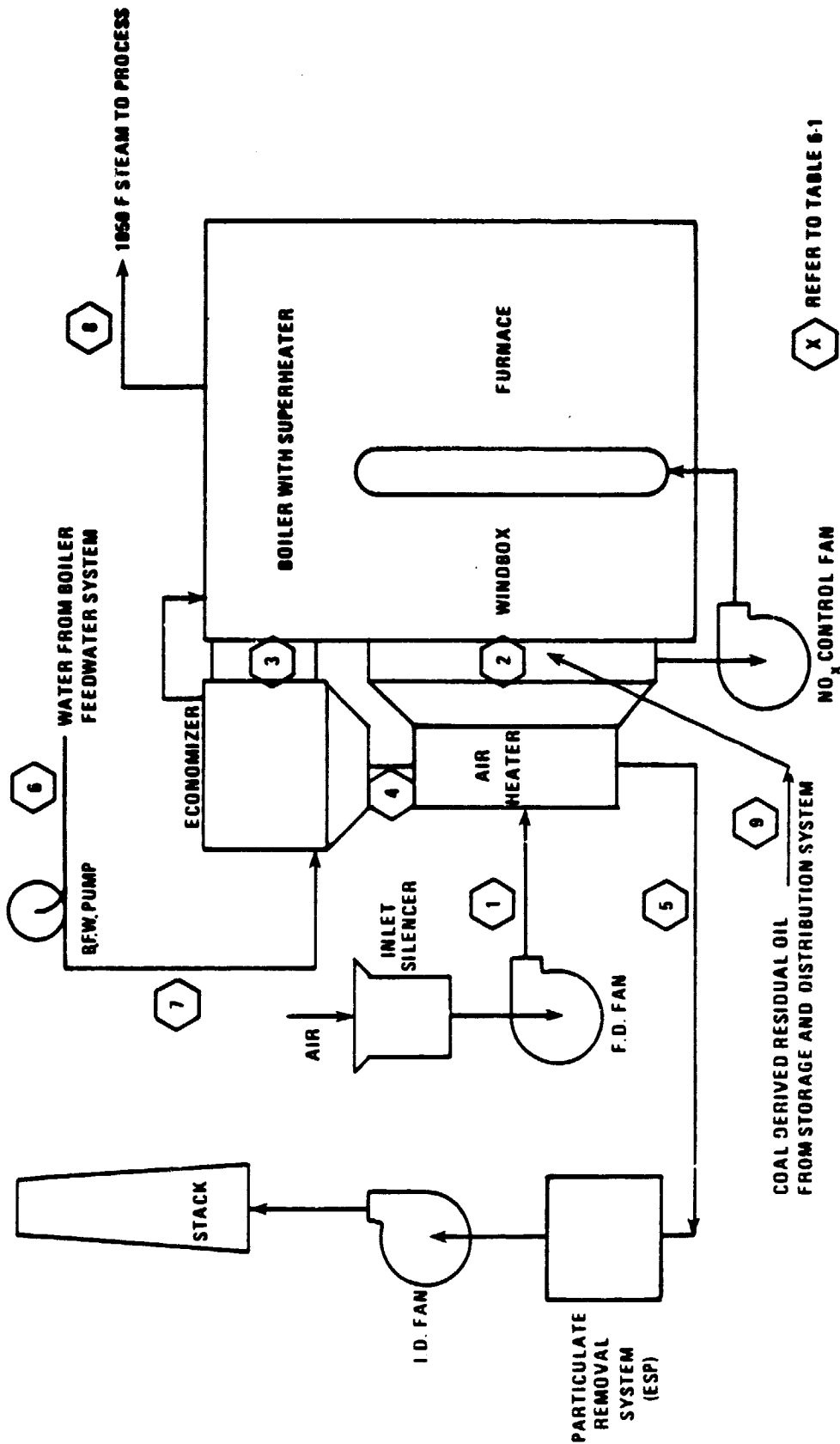


Figure IV-18 COAL DERIVED RESIDUAL OIL FIRED, 1050F STEAM GENERATOR

TABLE IV-17

COAL DERIVED RESIDUAL OIL FIRED, 1050F STEAM GENERATOR

OPERATING PARAMETERS

(500 MILLION BTU/HR)

<u>Stream Number</u>	<u>Flowrate (lb/hr)</u>	<u>Temperature (F)</u>	<u>Pressure (psia)</u>
1	482,800*	59	15.1
2	483,000	270	15.0
3	516,000	1000	14.7
4	516,000	500	14.5
5	516,000	300	14.3
6	391,000	250	30.0
7	391,000	258	2015.0
8	387,000	1050	1815.0
9	33,200	120	70.0

* 10% Excess Combustion Air

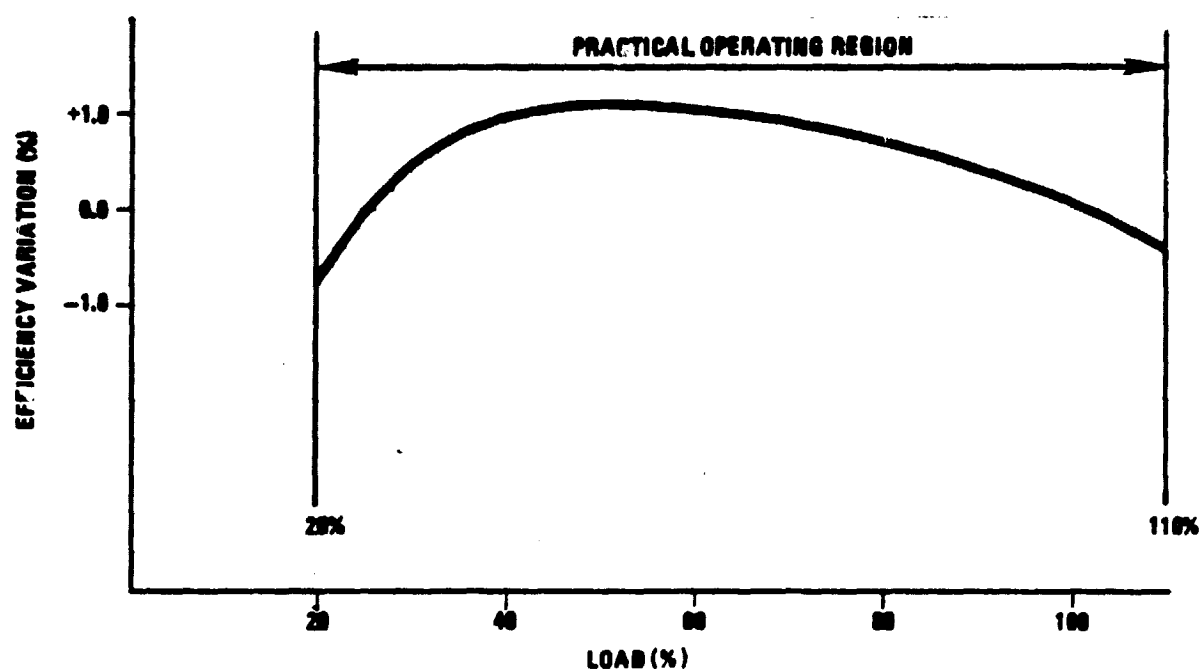


Figure IV-19 VARIATION OF THERMAL EFFICIENCY WITH PERCENT LOAD FOR THE COAL DERIVED RESIDUAL OIL FIRED, 1050 F STEAM GENERATOR

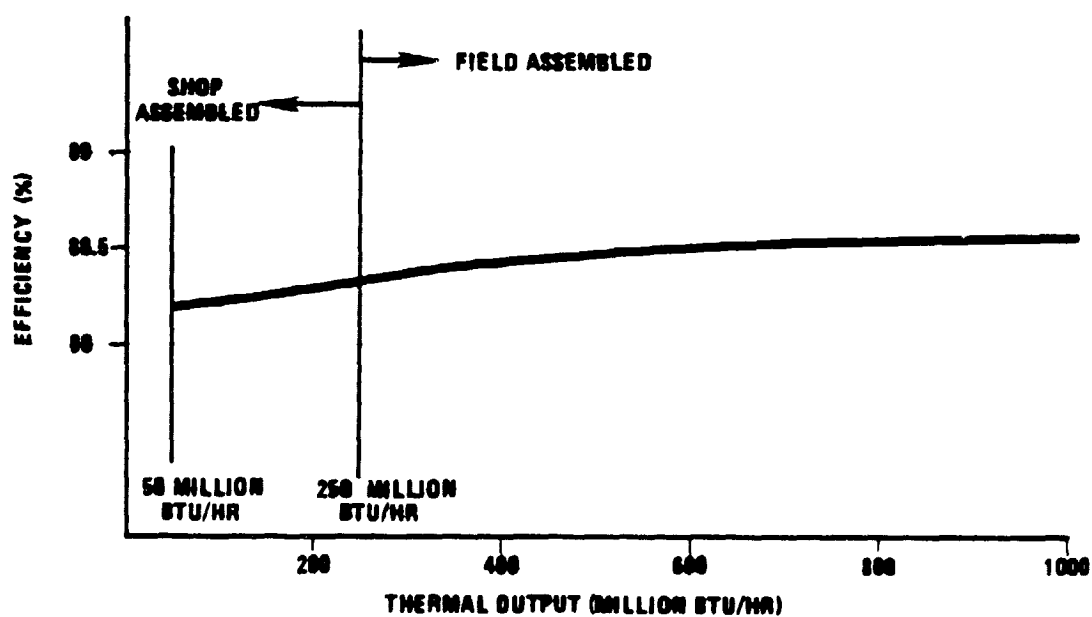


Figure IV-20 VARIATION OF DESIGN POINT EFFICIENCY WITH DESIGN POINT OUTPUT FOR THE COAL DERIVED RESIDUAL OIL FIRED, 1050 F STEAM GENERATOR

TABLE IV-18

COAL DERIVED RESIDUAL OIL FIRED, 1050F STEAM GENERATOR
ENVIRONMENTAL INTRUSION

<u>Stack Gas Emissions</u>	<u>Predicted Rate (lb/million Btu)</u>
Sulfur Dioxide	0.824
Nitrogen Oxides	0.5
Hydrocarbons	0.02
Carbon Monoxide	0.027
Particulates	0.1
<u>Wastes Discharged</u>	
Water (Blowdown)	6.9
Dry Solids	0.053
Wet Solids	0
<u>Water Required</u>	
(Exclusive of Boiler Feed Water)	0
<u>Steam Required (50 psig, 300F Condition)</u>	
Fuel Atomizing	17.6

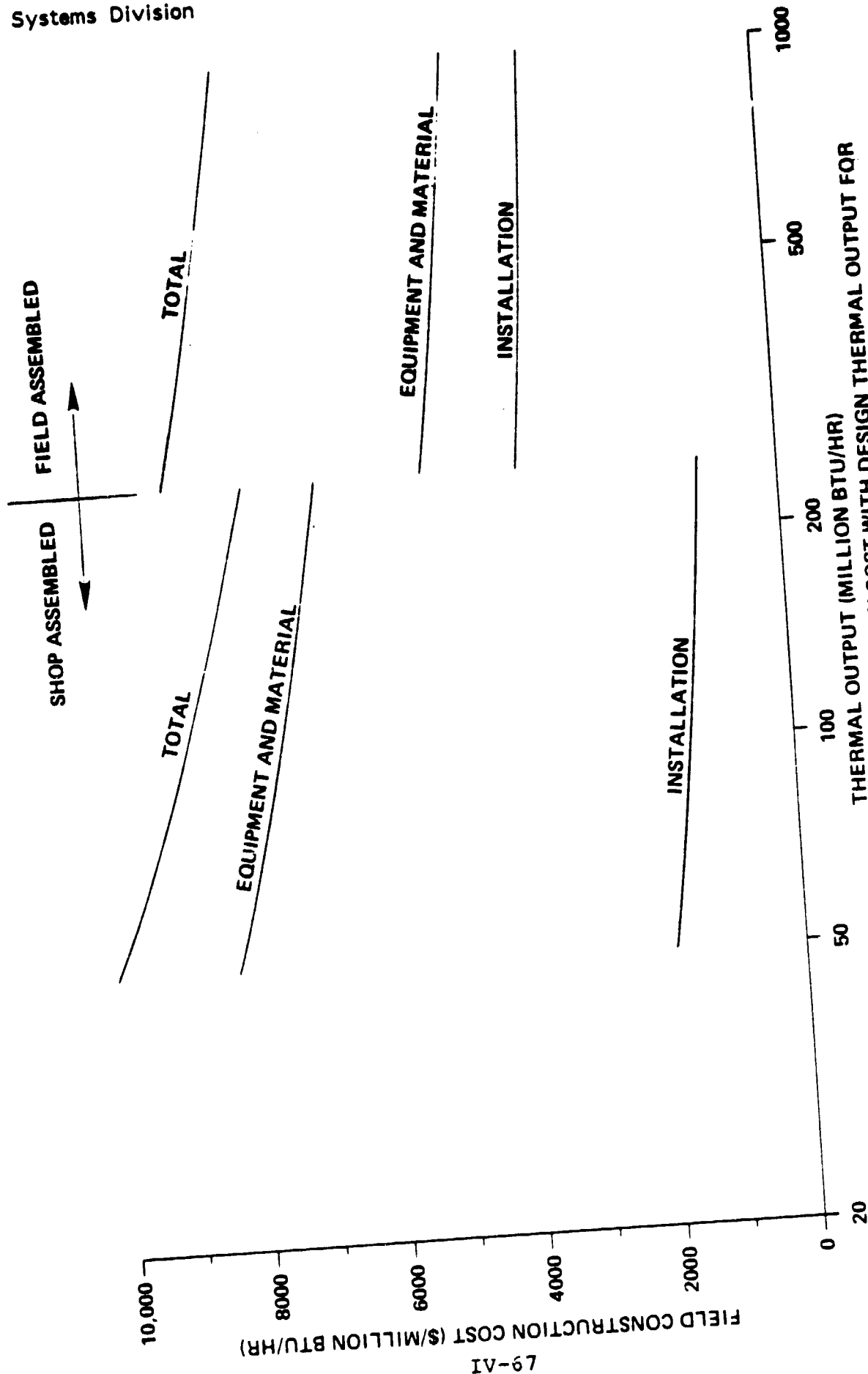


Figure IV-21 VARIATION OF FIELD CONSTRUCTION COST WITH DESIGN THERMAL OUTPUT FOR COAL-DERIVED RESIDUAL OIL FIRED, 1050 F STEAM GENERATOR

TABLE IV-19

COAL DERIVED RESIDUAL OIL FIRED, 1050F STEAM GENERATOR
FIELD CONSTRUCTION COST
(500 MILLION BTU/HR)

<u>ITEMS</u>	<u>DOLLARS</u>
Equipment	
Furnace, Field Erected (inc. boiler, economizer and air heater)	1,840,000
Particulate Removal (ESP)	106,000
Other Equipment	209,000
Civil/Structural	31,000
Piping/Instrumentation	<u>223,000</u>
Total Equipment and Materials	2,409,000
Direct Installation Labor (@ \$14/MH)	1,029,000
Indirects (@ 75% of Direct Labor)	<u>772,000</u>
Total Field Construction Cost (Mid-1978 Dollars)	4,210,000 =====

TABLE IV-20
COAL DERIVED RESIDUAL OIL FIRED, 1050F STEAM GENERATOR
FIELD CONSTRUCTION COST
(100 MILLION BTU/HR)

<u>ITEMS</u>	<u>DOLLARS</u>
Equipment	
Furnace, Shop Assembled (incl. boiler, economizer and air heater)	560,000
Particulate Removal (ESP)	23,000
Other Equipment	115,000
 Civil/Structural	 14,000
Piping/Instrumentation	<u>39,000</u>
Total Equipment and Materials	751,000
 Direct Installation Labor (@ \$14/MH)	 85,000
Indirects (@ 75% of Direct Labor)	<u>64,000</u>
 Total Field Construction Cost (Mid-1978 Dollars)	 900,000 =====

CASE 7
COAL DERIVED RESIDUAL OIL FIRED, 1800F HOT GAS GENERATOR

The hot gas generator, shown in Figure IV-22, is an advanced technology heat source system incorporating a coal derived residual oil fired furnace and a ceramic U-tube heat exchanger to heat high pressure air to 1800F. The system recirculates exhaust gas from the heat exchanger into the furnace to moderate its combustion gas temperature. A single furnace and heat exchanger are used in systems producing 50 to 125 million Btu/hr, with higher outputs requiring multiple units. The system's design and operating characteristics are as follows.

Characteristics

- Coal derived residual oil fired furnace with 10% excess air; high pressure fuel atomization
- Staged firing for nitrogen oxides emission control
- Oxygen content in the flue gases control excess air
- Air/fuel metering control
- Recirculating flue gases control working fluid outlet temperature
- U-tube heat exchanger including ceramic high temperature section and metal superalloy moderate temperature sections
- Tubular type, metal air heater
- Forced draft fan with inlet silencer
- Induced draft fan with exhaust stack
- Recirculation fan for cooled flue gases
- Electrically operated soot blowers using high temperature working fluid (air)
- Carbon steel ducting with insulating refractory
- Particulate removal system (ESP) to meet emission requirements

Design Point Performance

- Thermal output - 125 million Btu/hr
- Working fluid conditions
 - Inlet - 606 psia, 800F air
 - Outlet - 600 psia, 1800F air
- Thermal efficiency - 88.3%

Operating Parameters

Table IV-21 gives the flowrate, temperature and pressure of each of the major streams in the system. The stream numbers are identified on the system schematic diagram.

Permissible Range of Operation

The permissible range of operation and the variation in thermal efficiency over that range is the same for this system as for the coal derived residual oil fired, 1050F steam generator as shown in Figure IV-19.

Effect of Capacity on Efficiency

Design point efficiency is assumed to be constant over the range of thermal output considered because multiple units are used to achieve higher capacities.

Auxiliary Power Requirement

Electric power is required for the forced draft, induced draft and recirculation fans. The power requirement is 1.85 kWe per million Btu/hr.

Environmental Intrusion

Table IV-22 gives the stack gas emissions, wastes discharged, and requirements of water and atomizing steam for the heat source system. Data are expressed in pounds of material per million Btu gross energy input to the system (fuel higher heating value). Stack gas emissions for the heat source including a particulate removal system were calculated on the basis of fuel specifications defined for this study.

Flexibility and Reliability

This advanced technology heat source has flexibility and reliability characteristics similar to a current technology oil fired unit. Its characteristics are as follows.

- Fuel Flexibility. The heat source can be modified to fire a wide range of petroleum or coal derived distillate and residual oils as well as gaseous fuels of varying compositions and heating values. Modifications of the fans, ductwork and burner system would be required. Addition of an emission control system for sulfur removal might also be required for fuels with high sulfur content.
- Transition to Coal or Other Coal Derived Fuel. Modifications of the oil fired furnace to accept coal firing is not practical due to the differences in combustion and heat release characteristics and fuel handling equipment required. However, coal derived gaseous fuels can be fired as described in the previous paragraph.
- Operational Flexibility. The unit may be operated from 20% to 110% of design thermal output with only a small change in efficiency.
- Retrofit to Existing Plants. Retrofit potential is good because space requirements are low. However, it may be limited by special operational problems associated with the high temperature, ceramic heat exchanger.
- Retrofit of Technology Advancements. The system can be modified to incorporate advances in burner design and combustion air control technology.
- Siting Flexibility. The siting requirements are similar to those typical of an industrial plant. Rail excess is required for construction and fuel delivery. However, the system has no special requirements which will influence siting flexibility.
- Potential Reliability. Reliability is expected to be high since a majority of the components such as furnace, fans and air heaters are of conventional type. The ceramic heat exchanger is an advanced technology component which can be expected to function reliably once the problems associated with the materials of construction are solved. Due to modular design of the heat source, multiple units will be used for capacities greater than 125 million Btu/hr, resulting in increased reliability.

Space Requirements

The area and volume requirements for the heat source system are expressed as a function of the system thermal output capacity by the following equations,

$$\text{Area (sq ft)} = 2000 + 20C$$

$$\text{Volume (cu ft)} = 1700C$$

where C is equal to the system thermal output capacity in million Btu/hr. The area and volume requirements do not include the exhaust stack.

Maintenance and Overhaul

Scheduled maintenance and overhaul frequencies for the heat source system and the associated planned outages are as follows.

	<u>Maintenance</u>	<u>Overhaul</u>
Interval	12 months	60 months
Planned Outage Required	2 weeks	6 weeks

Capital and Operating Costs

- Capital Cost- Figure IV-23 shows field construction costs versus thermal output for the heat source system. The costs are broken down into equipment and material cost and installation costs. Installation costs include direct installation labor at \$14.00 per manhour plus 75% of direct labor costs for indirect field costs (distributables). Table IV-23 presents the cost breakdown for a system designed for 125 million Btu/hr thermal output capacity.
- Operating and Maintenance- Annual operating and maintenance costs for the system exclusive of fuel costs are estimated at \$234 per million Btu/hr design thermal output capacity of the heat source.

Construction and Installation Period

The construction and installation period required for the heat source is expressed as a function of the system thermal output capacity by the following equation:

$$M = \frac{C}{200} \times 20$$

where M is equal to construction and installation period in months and C is equal to system thermal output capacity in million Btu/hr.

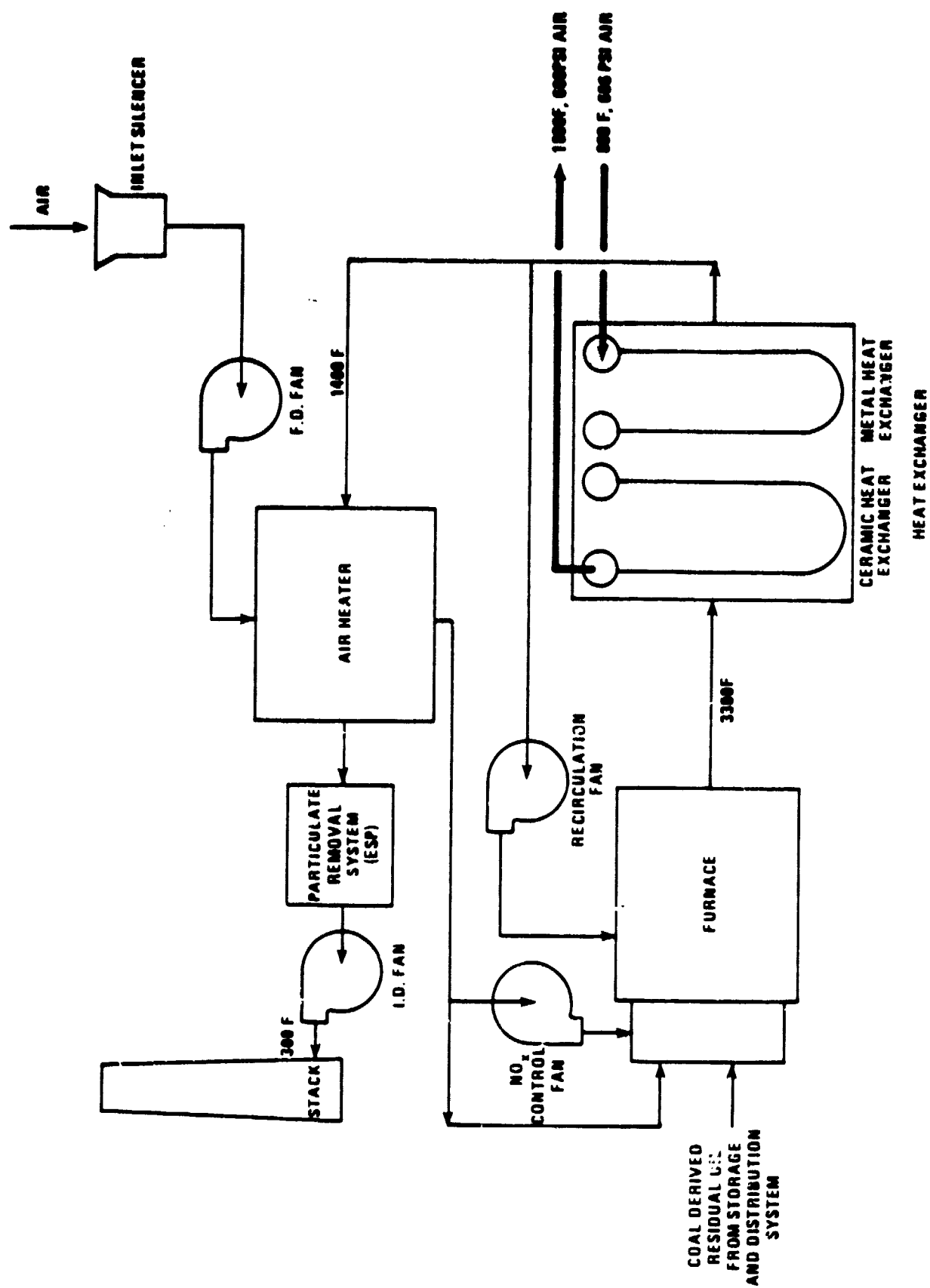


FIGURE IV-22 COAL DERIVED RESIDUAL OIL FIRED, 1800F HOT GAS GENERATOR

TABLE IV-21

COAL DERIVED RESIDUAL OIL FIRED, 1800F HOT GAS GENERATOR
OPERATING PARAMETERS
(125 MILLION BTU/HR)

<u>Stream Number</u>	<u>Flowrate (lb/hr)</u>	<u>Temperature (F)</u>	<u>Pressure (psia)</u>
1	120,700*	59	15.1
2	120,700	1340	15.0
3	208,000	3300	14.7
4	208,000	1400	14.6
5	79,000	1400	14.6
6	129,000	1400	14.6
7	129,000	300	14.5
8	462,000	800	606.0
9	462,000	1800	600.0
10	8,300	120	140.0

* 10% Excess Combustion Air

TABLE IV-22

COAL DERIVED RESIDUAL OIL FIRED, 1800F HOT GAS GENERATOR
ENVIRONMENTAL INTRUSION

<u>Stack Gas Emissions</u>	<u>Predicted Rate (lb/million Btu)</u>
Sulfur Dioxide	0.824
Nitrogen Oxides	0.5
Hydrocarbons	0.02
Carbon Monoxide	0.027
Particulates	0.1
<u>Wastes Discharged</u>	
Water (Blowdown)	0
Dry Solids	0.053
Wet Solids	0
<u>Water Required</u>	
(Exclusive of Boiler Feed Water)	0
<u>Steam Required (50 psig, 300F Condition)</u>	
Fuel Atomizing	17.6

COST IN MID-1978 DOLLARS

FIELD CONSTRUCTION COST (\$/MILLION BTU/HR)

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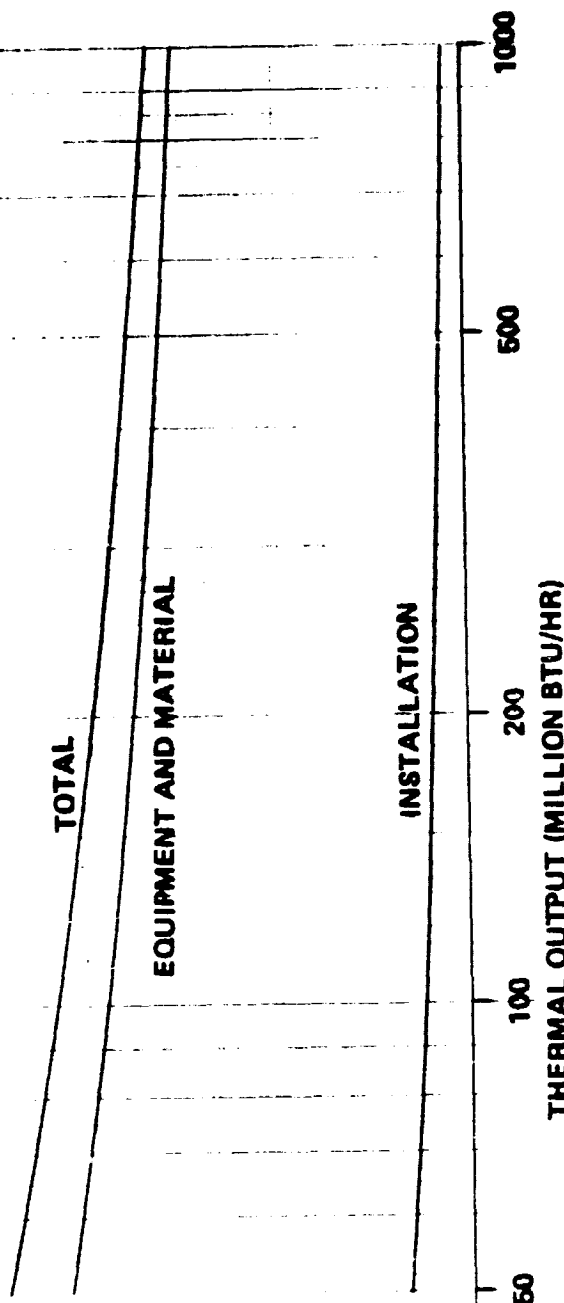


Figure IV-23 VARIATION OF FIELD CONSTRUCTION COST WITH DESIGN THERMAL OUTPUT FOR
COAL-DERIVED RESIDUAL OIL FIRED, 1800 F HOT GAS GENERATOR

TABLE IV-23

COAL DERIVED RESIDUAL OIL FIRED, 1800F HOT GAS GENERATOR

FIELD CONSTRUCTION COST

(125 MILLION BTU/HR)

<u>ITEMS</u>	<u>DOLLARS</u>
Equipment	
Furnace	332,000
Heat Exchanger	1,134,000
Air Heater	485,000
Particulate Removal (ESP)	27,000
Other Equipment	200,000
Civil/Structural	122,000
Piping/Instrumentation	<u>80,000</u>
Total Equipment and Materials	2,380,000
Direct Installation Labor (@ \$14/MH)	169,000
Indirects (@ 75% of Direct Labor)	<u>127,000</u>
Total Field Construction Cost (Mid-1978 Dollars)	2,676,000 =====

CASE 8
COAL DERIVED RESIDUAL OIL FIRED, 2200F HOT GAS GENERATOR

The hot gas generator, shown in Figure IV-24, is an advanced technology heat source system incorporating a coal derived residual oil fired furnace and a ceramic U-tube heat exchanger to heat high pressure air to 2200F. The system recirculates exhaust gas from the heat exchanger into the furnace to moderate its combustion gas temperature and includes an air preheater for heat recovery. A single furnace and heat exchanger are used in systems producing 50 to 125 million Btu/hr with higher outputs requiring multiple units. The system's design and operating characteristics are as follows.

Characteristics

- Coal derived residual oil fired furnace with 10% excess air; high pressure fuel atomization
- Staged firing for nitrogen oxides emission control
- Oxygen content in the flue gases control excess air
- Air/fuel metering control
- Recirculating flue gases control working fluid outlet temperature
- U-tube heat exchanger including ceramic high temperature section and metal superalloy moderate temperature sections
- Tubular type metal air heater
- Forced draft fan with inlet silencer
- Induced draft fan with exhaust stack
- Recirculation fan for cooled flue gases
- Electrically operated soot blowers using high temperature working fluid (air)
- Carbon steel ducting with insulating refractory
- Particulate removal system (ESP) to meet emission requirements

Design Point Performance

- Thermal output - 125 million Btu/hr
- Working fluid conditions
 - Inlet - 608 psia, 1200F air
 - Outlet - 600 psia, 2200F air
- Thermal efficiency - 88.3%

Operating Parameters

Table IV-24 gives the flowrate, temperature and pressure of each of the major streams in the system. The stream numbers are identified on the system schematic diagram.

Permissible Range of Operation

The permissible range of operation and the variation in thermal efficiency over that range is the same for this system as for the coal derived residual oil fired, 1050F steam generator as shown in Figure IV-19.

Effect of Capacity on Efficiency

Design point efficiency is assumed to be constant over the range of thermal output considered because multiple units are used to achieve higher capacities.

Auxiliary Power Requirement

Electric power is required for the forced draft, induced draft and recirculation fans. The power requirement is 2.34 kWe per million Btu/hr.

Environmental Intrusion

Table IV-25 gives the stack gas emissions, wastes discharged, and requirements of water and atomizing steam for the heat source system. Data are expressed in pounds of material per million Btu gross energy input to the system (fuel higher heating value). Stack gas emissions for the heat source including a particulate removal system were calculated on the basis of fuel specifications defined for this study.

Flexibility and Reliability

This advanced technology heat source has flexibility and reliability characteristics similar to a current technology oil fired unit. Its characteristics are as follows.

- Fuel Flexibility. The heat source can be modified to fire a wide range of petroleum or coal derived distillate and residual oils as well as gaseous fuels of varying compositions and heating values. Modifications of the fans, ductwork and burner system would be required. Addition of an emission control system for sulfur removal might also be required for fuels with high sulfur content.
- Transition to Coal or Other Coal Derived Fuel. Modifications of the oil fired furnace to accept coal firing is not practical due to the differences in combustion and heat release characteristics and fuel handling equipment required. However, coal derived gaseous fuels can be fired as described in the previous paragraph.
- Operational Flexibility. The unit may be operated from 20% to 110% of design thermal output with only a small change in efficiency.
- Retrofit to Existing Plants. Retrofit potential is good because space requirements are low. However, it may be limited by special operational problems associated with the high temperature, ceramic heat exchanger.
- Retrofit of Technology Advancements. The system can be modified to incorporate advances in burner design and combustion air control technology.
- Siting Flexibility. The siting requirements are similar to those typical of an industrial plant. Rail access is required for construction and fuel delivery. However, the system has no special requirements which will influence siting flexibility.
- Potential Reliability. Reliability is expected to be high since a majority of the components such as furnace, fans and air heaters are of conventional type. The ceramic heat exchanger is an advanced technology component which can be expected to function reliably once the problems associated with the materials of construction are solved. Due to modular design of the heat source, multiple units will be used for capacities greater than 125 million Btu/hr, resulting in increased reliability.

Space Requirements

The area and volume requirements for the heat source system are expressed as a function of the system thermal output capacity by the following equations,

$$\text{Area (sq ft)} = 2000 + 20C$$

$$\text{Volume (cu ft)} = 1700C$$

where C is equal to the system thermal output capacity in million Btu/hr. The area and volume requirements do not include the exhaust stack.

Maintenance and Overhaul

Scheduled maintenance and overhaul frequencies for the heat source system and the associated planned outages are as follows.

	<u>Maintenance</u>	<u>Overhaul</u>
Interval	12 months	60 months
Planned Outage Required	2 weeks	6 weeks

Capital and Operating Costs

- Capital Cost. Figure IV-25 shows field construction costs versus thermal output for the heat source system. The costs are broken down into equipment and material cost and installation costs. Installation costs include direct installation labor at \$14.00 per manhour plus 75% of direct labor costs for indirect field costs (distributables). Table IV-26 presents the cost breakdown for a system designed for 125 million Btu/hr thermal output capacity.
- Operating and Maintenance. The annual operating and maintenance costs for the system exclusive of fuel costs are estimated at \$234 per million Btu/hr thermal design output capacity of the heat source.

Construction and Installation Period

The construction and installation period required for the heat source is expressed as a function of the system thermal output capacity by the following equation:

$$M = \frac{C}{200} \times 20$$

where M is equal to construction and installation period in months and C is equal to system thermal output capacity in million Btu/hr.

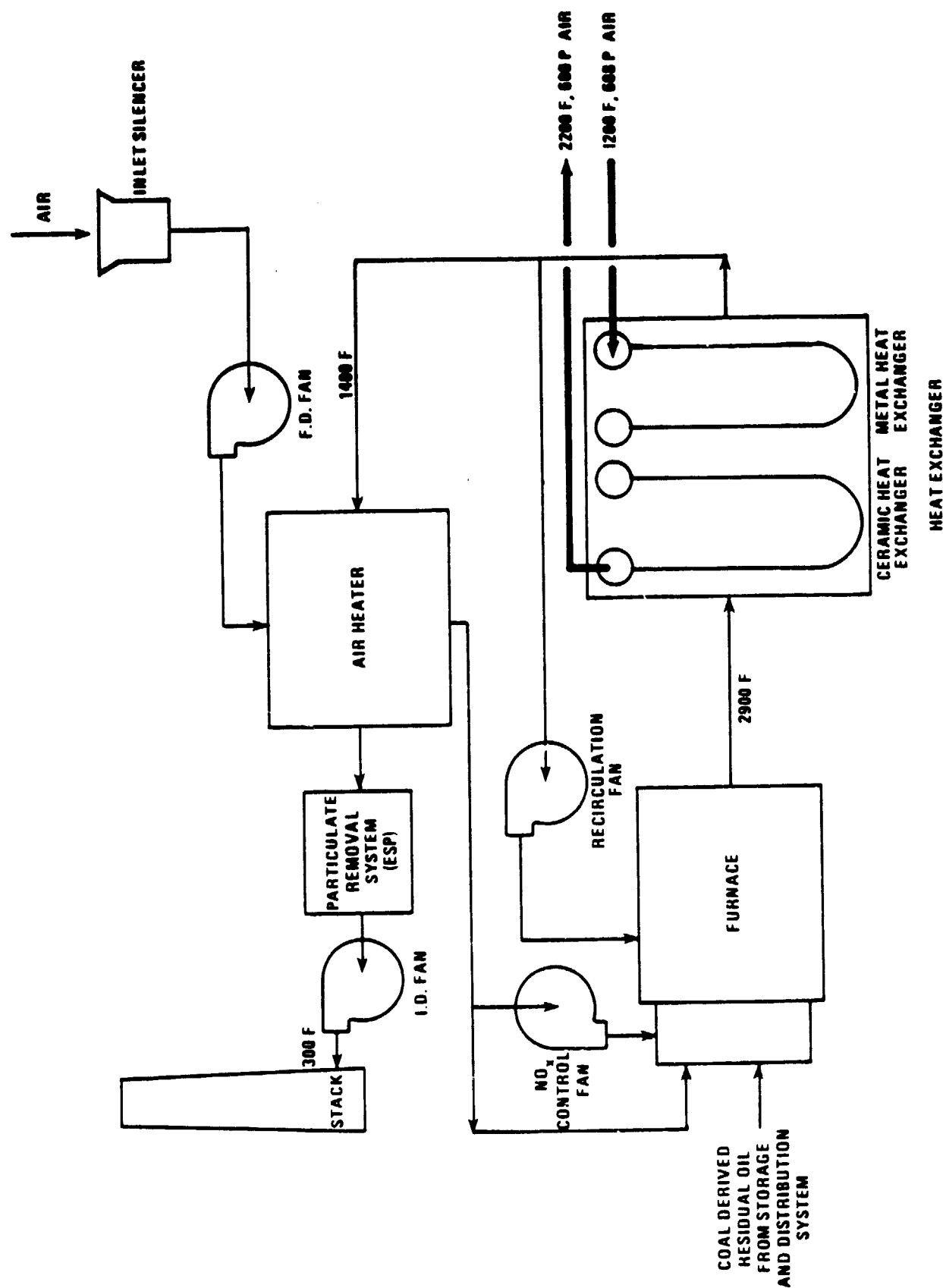


FIGURE IV-24 COAL DERIVED RESIDUAL OIL FIRED, 2200F HOT GAS GENERATOR

TABLE IV-24

COAL DERIVED RESIDUAL OIL FIRED, 2200F HOT GAS GENERATOR

OPERATING PARAMETERS

(125 MILLION BTU/HR)

<u>Stream Number</u>	<u>Flowrate (lb/hr)</u>	<u>Temperature (F)</u>	<u>Pressure (psia)</u>
1	120,700*	59	15.1
2	120,700	1340	15.0
3	268,000	2900	14.7
4	268,000	1400	14.6
5	139,000	1400	14.6
6	129,000	1400	14.6
7	129,000	300	14.5
8	447,000	1200	608.0
9	447,000	2200	600.0
10	8,300	120	140.0

* 10% Excess Combustion Air

TABLE IV-25

COAL DERIVED RESIDUAL OIL FIRED, 2200F HOT GAS GENERATOR
ENVIRONMENTAL INTRUSION

<u>Stack Gas Emissions</u>	<u>Predicted Rate (lb/million Btu)</u>
Sulfur Dioxide	0.824
Nitrogen Oxides	0.5
Hydrocarbons	0.02
Carbon Monoxide	0.027
Particulates	0.1
<u>Wastes Discharged</u>	
Water (Blowdown)	0
Dry Solids	0.053
Wet Solids	0
<u>Water Required</u>	
(Exclusive of Boiler Feed Water)	0
<u>Steam Required (50 psig, 300F Condition)</u>	
Fuel Atomizing	17.6

COST IN MID-1978 DOLLARS

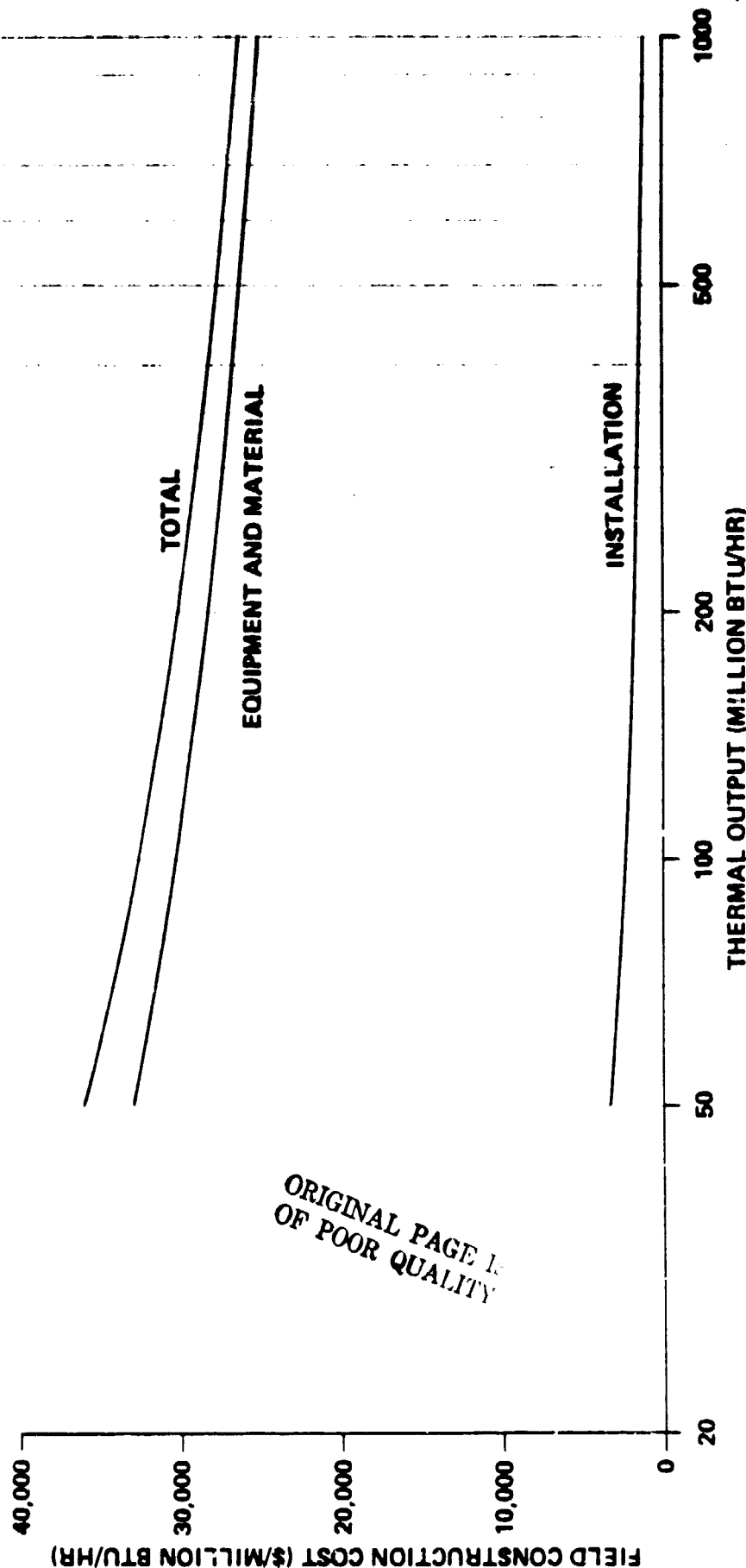


Figure IV-25 VARIATION OF FIELD CONSTRUCTION COST WITH DESIGN THERMAL OUTPUT FOR COAL-DERIVED RESIDUAL OIL FIRED, 2200 F HOT GAS GENERATOR

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TABLE IV-26

COAL DERIVED RESIDUAL OIL FIRED, 2200F HOT GAS GENERATOR

FIELD CONSTRUCTION COST

(125 MILLION BTU/HR)

<u>ITEMS</u>	<u>DOLLARS</u>
Equipment	
Furnace	332,000
Heat Exchanger	2,443,000
Air Heater	485,000
Particulate Removal (ESP)	27,000
Other Equipment	242,000
Civil/Structural	122,000
Piping/Instrumentation	<u>80,000</u>
Total Equipment and Materials	3,731,000
Direct Installation Labor (@ \$14/MH)	172,000
Indirects (@ 75% of Direct Labor)	<u>129,000</u>
Total Field Construction Cost (Mid-1978 Dollars)	4,032,000 =====

CASE 9
COAL DERIVED RESIDUAL OIL FIRED, 2400F THERMIONIC
CONVERTER HEAT SOURCE

The heat source system shown in Figure IV-26 incorporates an advanced technology coal derived residual oil fired furnace, a high temperature ceramic air preheater, and a steam generator. The system supplies heat to thermionic converter operating at 2400F located within the furnace and produces 700F steam. Its design and operating characteristics are as follows.

Characteristics

- Vertical standing, coal derived residual oil fired furnace with provision to install vertical heat pipes in the furnace walls and curtains
- Provision to install thermionic converters on top of the furnace
- Furnace with heat pipes is enclosed in casing with insulation
- Burners are located on two opposing walls with secondary air for nitrogen oxides emission control introduced into the furnace
- Forced draft and induced draft fans
- U-tube ceramic and superalloy high temperature air heater and carbon steel low temperature air heater
- Steam generator located between two stages of air heaters
- Boiler feed pump

Design Point Performance

- Thermal output
 - Thermionic converters - 104 million Btu/hr
 - Steam generation - 21 million Btu/hr
 - Total output - 125 million Btu/hr
- Working fluid conditions (steam generation)
 - Inlet - 15 psig, 250F water
 - Outlet - 600 psig, 700F steam
- Thermal efficiency - 88.3%

Operating Parameters

Table IV-27 gives the flowrate, temperature and pressure for each of the major streams in the system. The stream numbers are identified on the system schematic diagram. Figure IV-27 shows the distribution of various thermal outputs from a typical thermionic furnace.

Permissible Range of Operation

The permissible range of operation and thermal efficiency over that range is the same for this system as for the coal derived residual oil fired, 1050F steam generator as shown in Figure IV-19.

Effect of Capacity on Efficiency

The design point thermal efficiency varies slightly with thermal output capacity due to variation in furnace radiation losses. The variation for this system is the same as that shown in Figure IV-20 for the coal derived residual oil fired, 1050F steam generator.

Auxiliary Power Requirement

Electric power is required for the system fans and boiler feedwater pump. The power requirement is 1.3 kWe per million Btu/hr.

Environmental Intrusion

Table IV-28 gives the stack gas emissions, wastes discharged, and requirements of water and atomizing steam for the heat source system. Data are expressed in pounds of material per million Btu gross energy input to the system (fuel higher heating value). Stack gas emissions for the heat source including a particulate removal system were calculated on the basis of fuel specifications defined for this study.

Flexibility and Reliability

This advanced technology heat source has flexibility and reliability characteristics similar to a current technology oil fired unit. Its characteristics are as follows.

- Fuel Flexibility. The heat source can be modified to fire a wide range of petroleum or coal derived distillate and residual oils as well as gaseous fuels of varying compositions and heating values.

Modifications of the fans, ductwork and burner system would be required. Addition of an emission control system for sulfur removal might also be required for fuels with high sulfur content.

- Transition to Coal or Other Coal Derived Fuel. Modifications of the oil fired furnace to accept coal firing is not practical due to the differences in combustion and heat release characteristics and fuel handling equipment required. However, coal derived gaseous fuels can be fired as described in the previous paragraph.
- Operational Flexibility. The unit may be operated from 20% to 110% of design thermal output with only a small change in efficiency.
- Retrofit to Existing Plants. Retrofit potential is good because space requirements are low. However, it may be limited by special operational problems associated with the high temperature, ceramic heat exchanger.
- Retrofit of Technology Advancements. The system can be modified to incorporate advances in burner design and combustion air control technology.
- Siting Flexibility. The siting requirements are similar to those typical of an industrial plant. Rail access is required for construction and fuel delivery. However, the system has no special requirements which will influence siting flexibility.
- Potential Reliability. Reliability is expected to be high since a majority of the components such as furnace, fans and air heaters are of conventional type. The ceramic heat exchanger is an advanced technology component which can be expected to function reliably once the problems associated with the materials of construction are solved.

Space Requirements

The area and volume requirements for the heat source system are expressed as a function of the system thermal output capacity by the following equations,

$$\text{Area (sq ft)} = 32C$$

$$\text{Volume (cu ft)} = 1920C$$

where C is equal to the system thermal output capacity in million Btu/hr. The area and volume requirements do not include the exhaust stack.

Maintenance and Overhaul

Scheduled maintenance and overhaul frequencies for the heat source system and the associated planned outages are as follows.

	<u>Maintenance</u>	<u>Overhaul</u>
Interval	12 months	60 months
Planned Outage Required	2 weeks	6 weeks

Capital and Operating Costs

- Capital Cost. Figure IV-28 shows field construction costs versus thermal output for the heat source system. The costs are broken down into equipment and material cost and installation costs. Installation costs include direct installation labor at \$14.00 per manhour plus 75% of direct labor costs for indirect field costs (distributables). Table IV-29 presents the cost breakdown for a system designed for 125 million Btu/hr thermal output capacity.
- Operating and Maintenance. The annual operating and maintenance costs for the system exclusive of fuel costs are estimated at \$321 per million Btu/hr thermal design output capacity of the heat source.

Construction and Installation Period

The construction and installation period required for the heat source is expressed as a function of the system thermal output capacity by the following equation:

$$M = \frac{C}{200} \times 26$$

where M is equal to construction and installation period in months and C is equal to system thermal output capacity in million Btu/hr.

Alternative Thermionic Converter Heat Source

An alternative system to provide heat to thermionic converters (Case 9A) is shown in Figure IV-29. Table IV-30 gives the flowrate, temperature and pressure of each of the major streams

in the system. The system preheats the combustion air to 1400F instead of 2200F used in the baseline case (Case 9). As a result, the ceramic material air heater used in the Case 9 is not required for Case 9A. The following compares the performance and cost of the two cases:

	<u>Case 9</u>	<u>Case 9A</u>
Thermal Output (Million Btu/hr)		
To THX	104	77
To Steam	<u>21</u>	<u>48</u>
Total	125	125
Thermal Efficiency	88.3%	88.3%
Relative Cost	1.0	0.83

Table IV-31 presents the cost breakdown for the alternate system designed for 125 million Btu/hr thermal output capacity.

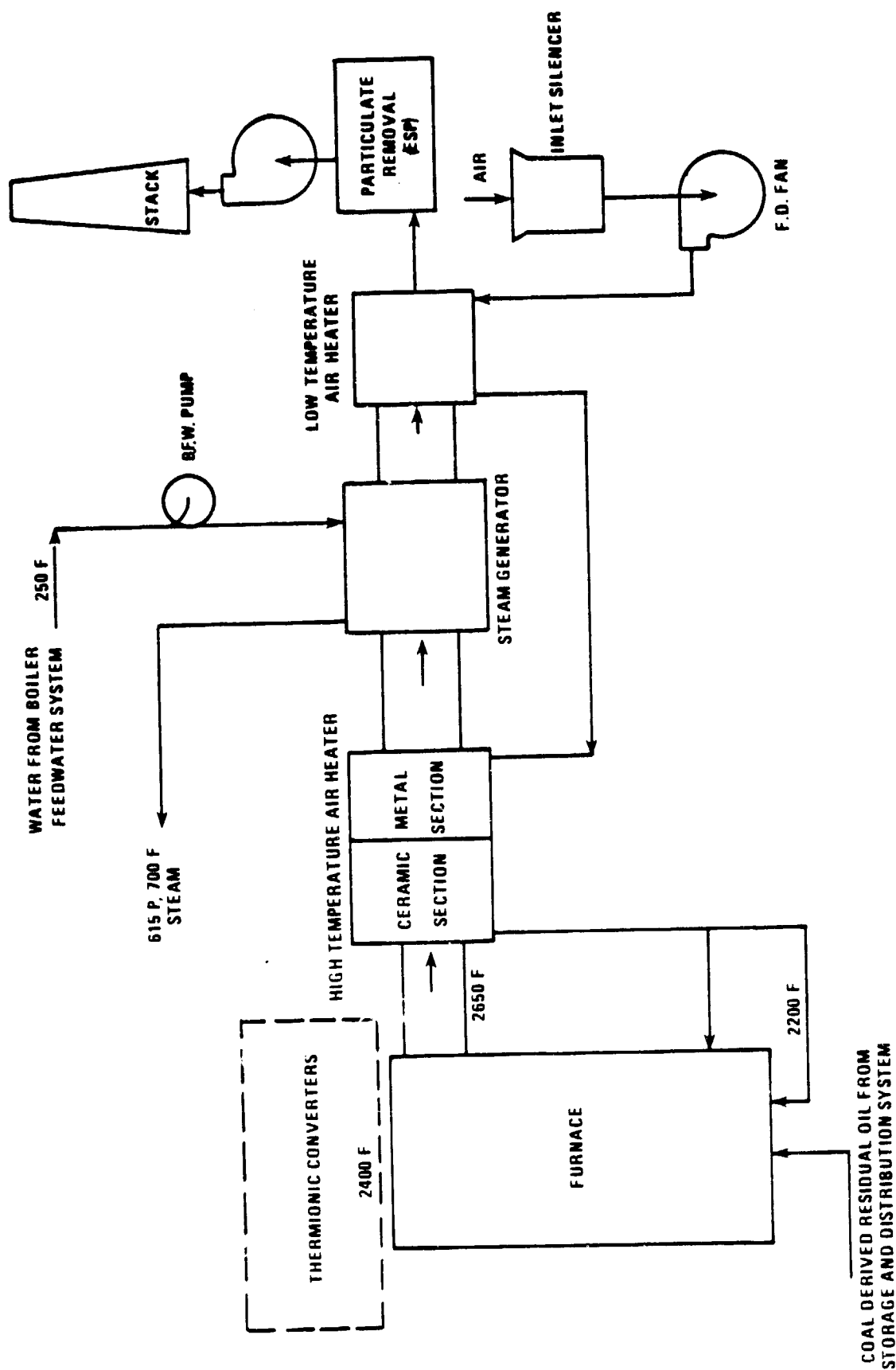


FIGURE IV-26 COAL DERIVED RESIDUAL OIL FIRED, 2400F THERMIONIC CONVERTER HEAT SOURCE

TABLE IV-27
COAL DERIVED RESIDUAL OIL FIRE), 2400F THERMIONIC
CONVERTER HEAT SOURCE - OPERATING PARAMETERS
(125 MILLION BTU/HR)

<u>Stream Number</u>	<u>Flowrate (lb/hr)</u>	<u>Temperature (F)</u>	<u>Pressure (psia)</u>
1	120,700*	59	15.2
2	120,700	300	15.1
3	120,700	2200	15.0
4	129,000	2650	14.8
5	129,000	1100	14.7
6	129,000	500	14.6
7	129,000	300	14.5
8	19,500	250	30.0
9	18,600	700	615.0
10	8,300	120	140.0

* 10% Excess Combustion Air

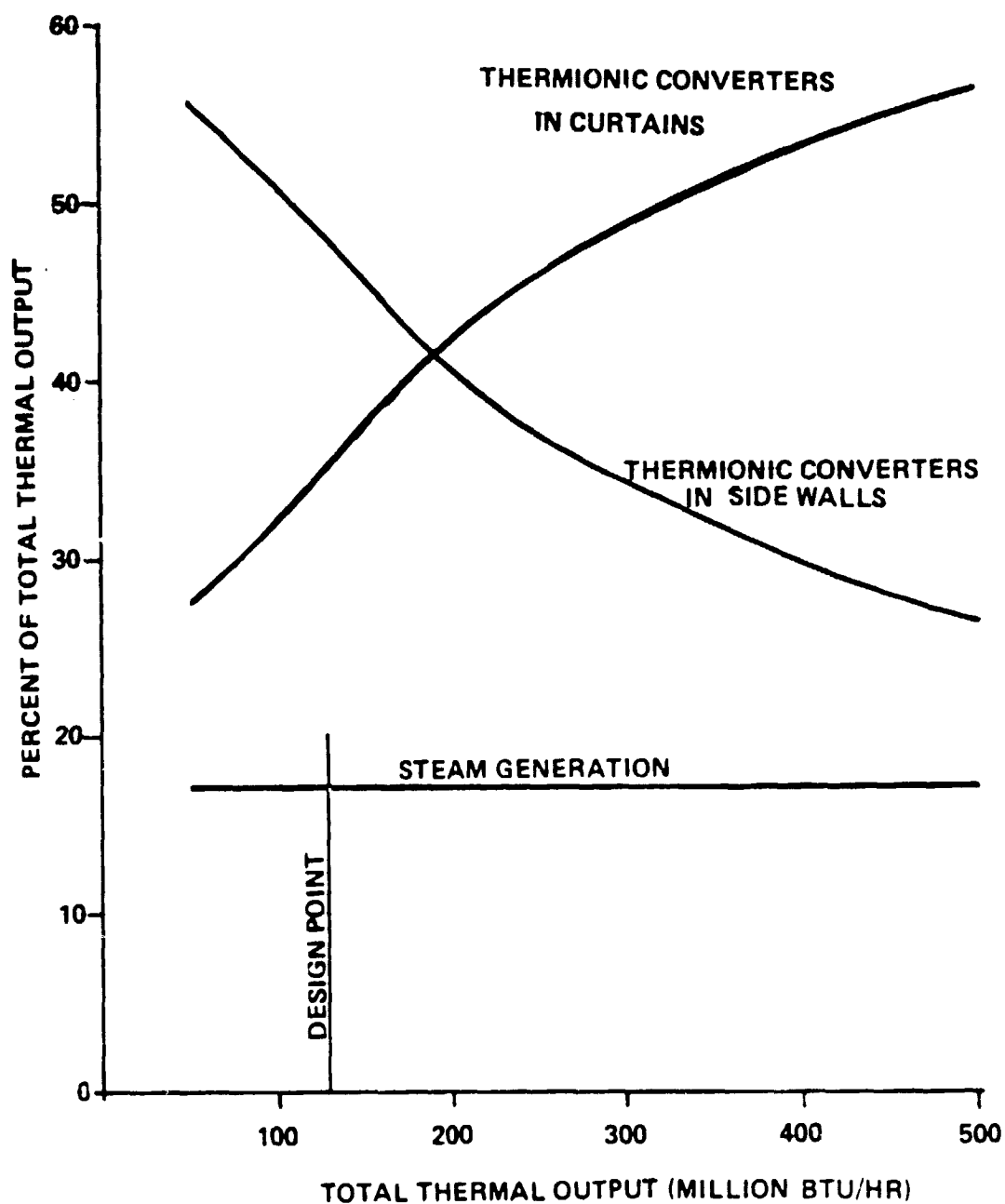


Figure IV-27
DISTRIBUTION OF TOTAL THERMAL OUTPUT OF THE COAL DERIVED
OIL FIRED, 2400 F THERMIONIC CONVERTER HEAT SOURCE

TABLE IV-28

COAL DERIVED RESIDUAL OIL FIRED, 2400F THERMIONIC
CONVERTER HEAT SOURCE
ENVIRONMENTAL INTRUSION

<u>Stack Gas Emissions</u>	<u>Predicted Rate (lb/million Btu)</u>
Sulfur Dioxide	0.824
Nitrogen Oxides	0.5
Hydrocarbons	0.02
Carbon Monoxide	0.027
Particulates	0.1
<u>Wastes Discharged</u>	
Water (Blowdown)	1.3
Dry Solids	0.053
Wet Solids	0
<u>Water Required</u>	
(Exclusive of Boiler Feed Water)	0
<u>Steam Required (50 psig, 300F Condition)</u>	
Fuel Atomizing	17.6

COST IN MID-1978 DOLLARS

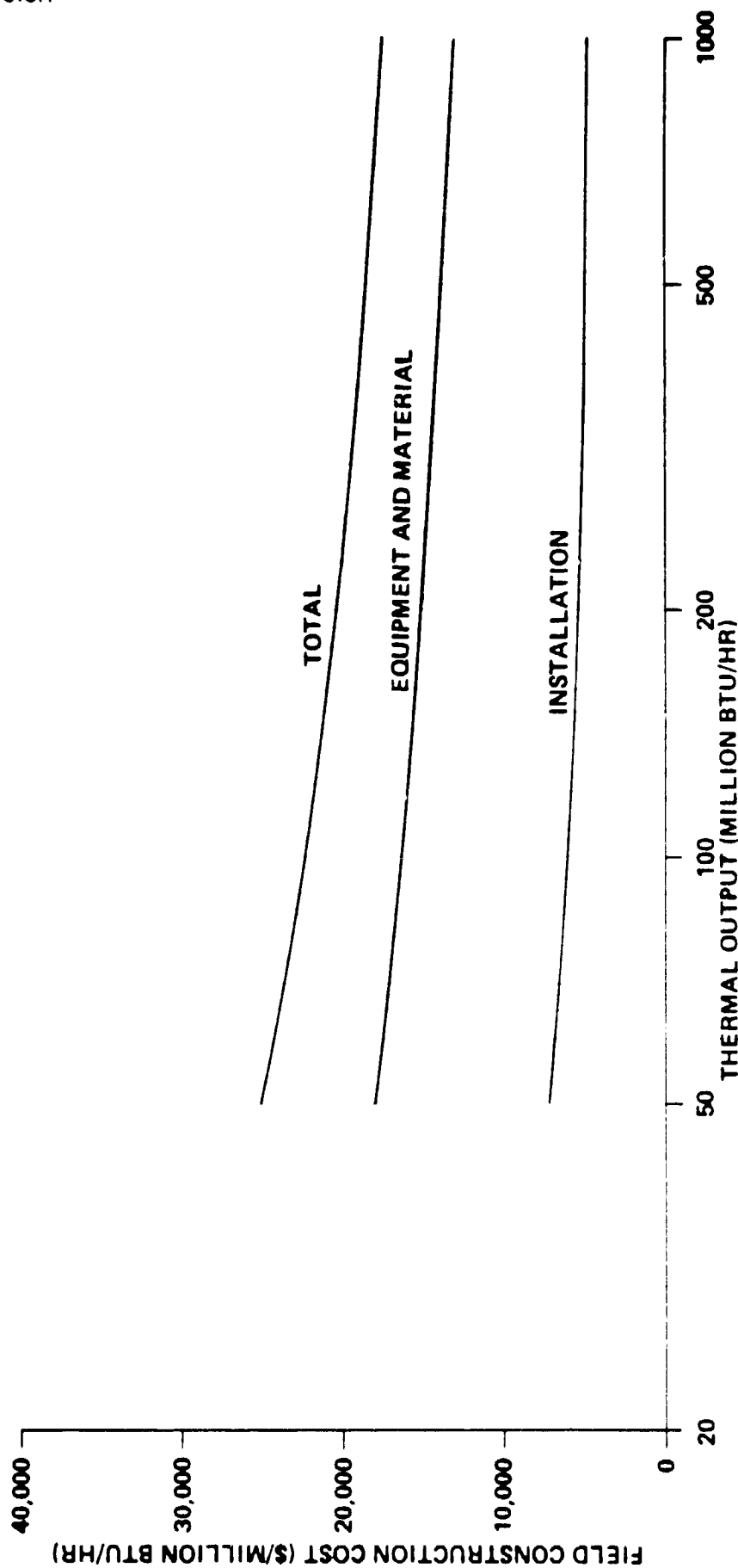


Figure IV-28 VARIATION OF FIELD CONSTRUCTION COST WITH DESIGN THERMAL OUTPUT FOR COAL-DERIVED RESIDUAL OIL FIRED, 2400 F THERMIONIC CONVERTER HEAT SOURCE

TABLE IV-29

COAL DERIVED RESIDUAL OIL FIRED, 2400F THERMIONIC
CONVERTER HEAT SOURCE
FIELD CONSTRUCTION COST
(125 MILLION BTU/HR)

<u>ITEMS</u>	<u>DOLLARS</u>
Equipment	
Furnace	726,000
Air Heater, High Temperature	731,000
Low Temperature	44,000
Steam Generator	100,000
Particulate Removal (ESP)	27,000
Other Equipment	144,000
 Civil/Structural	 120,000
Piping/Instrumentation	<u>93,000</u>
Total Equipment and Materials	1,985,000
 Direct Installation Labor (@ \$14/MH)	 420,000
Indirects (@ 75% of Direct Labor)	<u>315,000</u>
 Total Field Construction Cost (Mid-1978 Dollars)	 2,720,000 =====

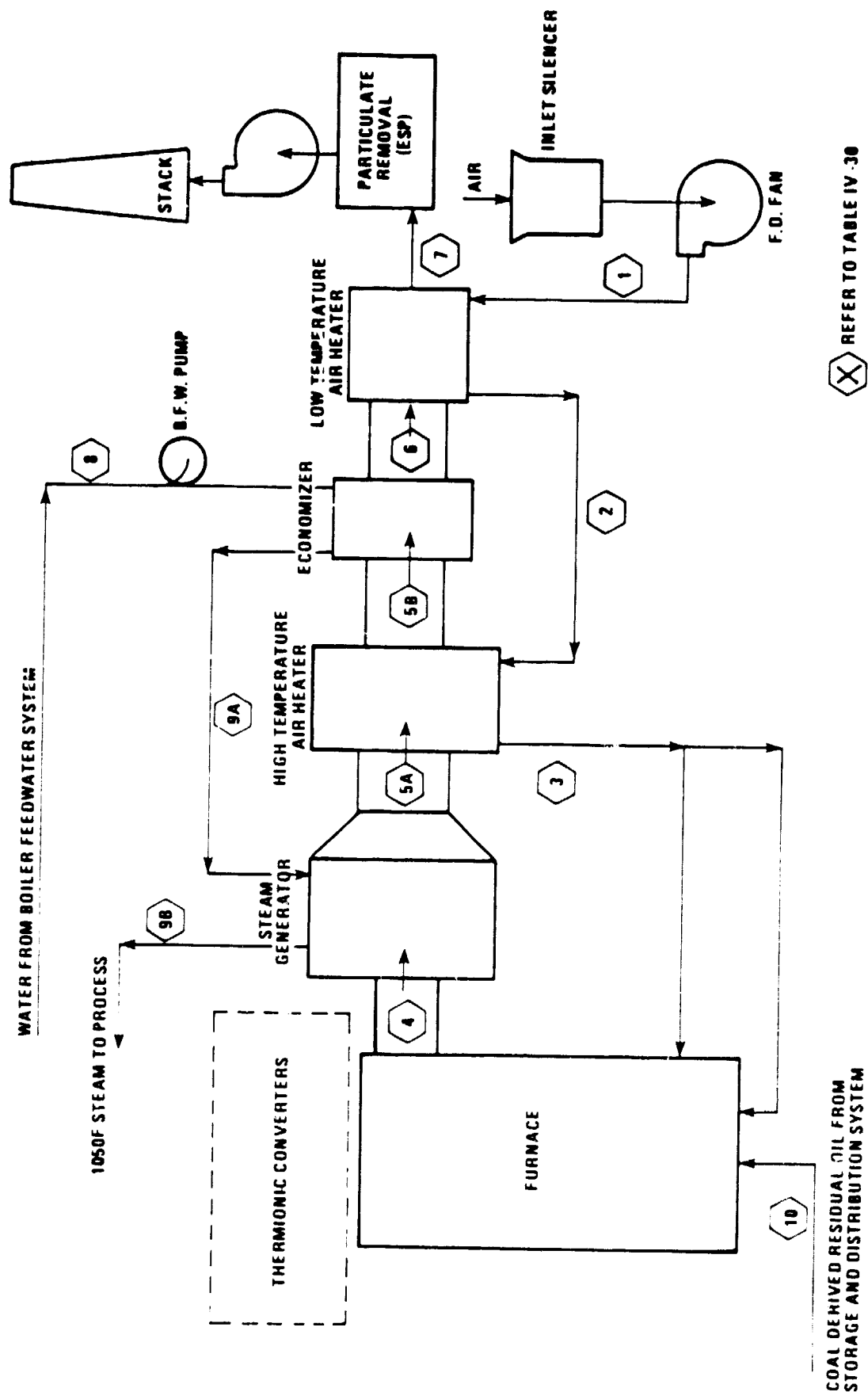


Figure IV-29 COAL DERIVED RESIDUAL OIL FIRED, 2400F THERMIONIC CONVERTER ALTERNATE HEAT SOURCE (WITHOUT CERAMIC AIR HEATER)

TABLE IV-30
COAL DERIVED RESIDUAL OIL FIRED, 2400F THERMIONIC
CONVERTER ALTERNATE HEAT SOURCE
(WITHOUT CERAMIC AIR HEATER)
OPERATING PARAMETERS
(125 MILLION BTU/HR)

<u>Stream Number</u>	<u>Flowrate (lb/hr)</u>	<u>Temperature (F)</u>	<u>Pressure (psia)</u>
1	120,700*	59	15.2
2	120,700	420	15.1
3	120,700	1400	15.0
4	129,000	2650	14.8
5A	129,000	1700	14.7
5B	129,000	880	14.6
6	129,000	580	14.6
7	129,000	300	14.5
8	40,000	250	30.0
9A	40,000	540	1975.0
9B	38,000	1050	1815.0
10	8,300	120	140.0

* 10% Excess Combustion Air

TABLE IV-31

COAL DERIVED RESIDUAL OIL FIRED, 2400F THERMIONIC
CONVERTER ALTERNATE HEAT SOURCE
(WITHOUT CERAMIC AIR HEATER)
FIELD CONSTRUCTION COST
(125 MILLION BTU/HR)

<u>ITEMS</u>	<u>DOLLARS</u>
Equipment	
Furnace	513,000
Air Heater, High Temperature	273,000
Low Temperature	100,000
Steam Generator	331,000
Particulate Removal	27,000
Other Equipment	179,000
Civil/Structural	120,000
Piping/Instrumentation	<u>93,000</u>
Total Equipment and Materials	1,636,000
Direct Installation Labor (@ \$14/MH)	350,000
Indirects (@ 75% of Direct Labor)	<u>263,000</u>
Total Field Construction Cost (Mid-1978 Dollars)	2,249,000 =====

CASE 10
COAL FIRED, 950F STEAM GENERATOR

The coal fired, 950F steam generator shown in Figure IV-30, is a current technology high pressure industrial boiler system including an economizer and air heater for heat recovery. The system requires a flue gas sulfur dioxide scrubber to meet emission requirements.* It incorporates a stoker-fired boiler for thermal outputs ranging from 50 to 150 million Btu/hr. Higher capacity systems include a pulverized coal fired boiler. The design and operating characteristics of the system are as follows.

Characteristics

The following characteristics describe the system which includes a stoker-fired boiler (thermal output less than 150 million Btu/hr).

- Water tube, natural circulation with water-cooled furnace walls
- Field assembled construction
- Spreader stoker with integrated plenum
- Spray type attemperator controls superheater steam temperature
- Externally located economizer
- Forced draft fan with inlet silencer
- Externally located tubular air heater
- Cyclone for flue gas particulate removal
- Induced draft fan for balanced draft operation with stack
- Air/fuel metering control
- Three element feedwater control
- Manually operated soot blowers

*The sulfur dioxide scrubber is not included as part of this heat source. It is a balance of plant system.

- Stack gas oxygen content controls excess air at 35%
- Building enclosure for major equipment

The characteristics of the system which includes a pulverized coal fired boiler are as follows (thermal output greater than 150 million Btu/hr).

- Water tube, natural circulation with water-cooled furnace walls
- Field assembled construction
- Pulverizer with primary air fans
- Pulverized coal burners
- Spray type attemperator controls superheater steam temperature
- Externally located economizer
- Forced draft fan with inlet silencer
- Externally located tubular air heater
- Cyclone for flue gas particulate removal
- Induced draft fan for balanced draft operation with stack
- Air/fuel metering control
- Three element feedwater control
- Electrically operated soot blowers
- Stack gas oxygen content controls excess air at 25%

Design Point Performance

- Thermal output - 500 million Btu/hr
- Working fluid conditions
 - Inlet - 15 psig, 250F water
 - Outlet - 1200 psig, 950F steam
- Thermal efficiency - 85% (CTAS ground rule)

Operating Parameters

Table IV-32 gives the flowrate, temperature and pressure for each of the major streams in the system. The stream numbers are identified on the system schematic diagram.

Permissible Range of Operation

Figure IV-31 shows the variation in thermal efficiency over the permissible range of operation.

Effect of Capacity on Efficiency

The variation in design point efficiency over the range of thermal output considered is shown in Figure IV-32. The efficiency of the pulverized coal fired system varies slightly due to change in radiation losses. The smaller, stoker-fired unit has a lower thermal efficiency due to higher excess air required and lower combustion efficiency.

Auxiliary Power Requirements

Electric power is required for the system fans, pulverizer and boiler feed pumps. The power required is:

<u>Thermal Output</u> <u>(Million Btu/Hr)</u>	<u>Electric Power Required</u> <u>(kWe/Million Btu/Hr)</u>
50 - 150	3.5
150 - 1000	4.3

Environmental Intrusion

Table IV-33 gives the stack gas emissions, wastes discharged, and requirements of water and atomizing steam for the heat source system. Data are expressed in pounds of material per million Btu gross energy input to the system (fuel higher heating value). Stack gas emissions for the heat source including a particulate removal system were calculated on the basis of fuel specifications defined for this study. The sulfur dioxide emission level includes the effect of incorporating a sulfur dioxide scrubber system.

Flexibility and Reliability

This current technology heat source for cogeneration applications represents a baseline system to which the advanced technology cogeneration heat sources will be compared. Its characteristics are as follows.

- Fuel Flexibility. Both the pulverized coal fired and smaller stoker fired units can accept a wide range of coals. Increased fuel feeding capability would be required for subbituminous and lignite coals which have lower heat content. Stoker fired units can also be modified to fire wood and waste solid fuels.
- Transition to Coal Derived Fuel. Modifications of conventional coal fired units to accept coal derived gaseous or liquid fuel firing is not practical due to the differences in combustion and heat release characteristics and fuel handling equipment required.
- Operational Flexibility. The unit may be operated from 20% to 110% of design thermal output with only a small change in efficiency.
- Retrofit to Existing Plants. Retrofit potential is limited by the large space requirements and the operational and safety problems associated with storage and handling of coal.
- Retrofit of Technology Advancements. The system can be modified to incorporate advances in burner design and combustion air control technology.
- Siting Flexibility. The siting requirements are similar to those typical of an industrial plant. Rail access is required for construction and fuel delivery. Water must be available for boiler feed water makeup. However, the system has no special requirements which will influence siting flexibility.
- Potential Reliability. Reliability has been shown historically to be high. Multiple units can be used to increase reliability without large cost penalties because capital and operating costs are relatively insensitive to unit size.

Space Requirements

The area and volume requirements for the heat source system are expressed as a function of the system thermal output capacity by the following equations,

$$\begin{aligned} \text{Area (sq ft)} &= 40C & (50 \leq C \leq 150) \\ &= 19C & (C > 150) \\ \\ \text{Volume (cu ft)} &= 2400C & (50 \leq C \leq 150) \\ &= 2550C & (C > 150) \end{aligned}$$

where C is equal to the system thermal output capacity in million Btu/hr. The area and volume requirements do not include the exhaust stack.

Maintenance and Overhaul

Scheduled maintenance and overhaul frequencies for the heat source system and the associated planned outages are as follows.

	<u>Maintenance</u>	<u>Overhaul</u>
Interval	6 months	36 months
Planned Outage Required	2 weeks	6 weeks

Capital and Operating Costs

- Capital Cost. Figure IV-33 shows field construction costs versus thermal output for the heat source system. The costs are broken down into equipment and material cost and installation costs. Installation costs include direct installation labor at \$14.00 per manhour plus 75% of direct labor costs for indirect field costs (distributables). Table IV-34 presents the cost breakdown of a system for 500 million Btu/hr thermal output capacity and Table IV-35 presents the cost breakdown of a system for 100 million Btu/hr thermal output capacity.
- Operating and Maintenance. Annual operating and maintenance costs for the system exclusive of fuel costs are estimated at \$292 per million Btu/hr design thermal output capacity of the heat source.

Construction and Installation Period

The construction and installation period required for the heat source is expressed as a function of the system thermal output capacity by the following equations:

$$M = \frac{C}{150} \times 22 \quad (50 \leq C \leq 150)$$

$$M = \frac{C}{200} \times 26 \quad (C > 150)$$

where M is equal to construction and installation period in months and C is equal to system thermal output capacity in million Btu/hr.

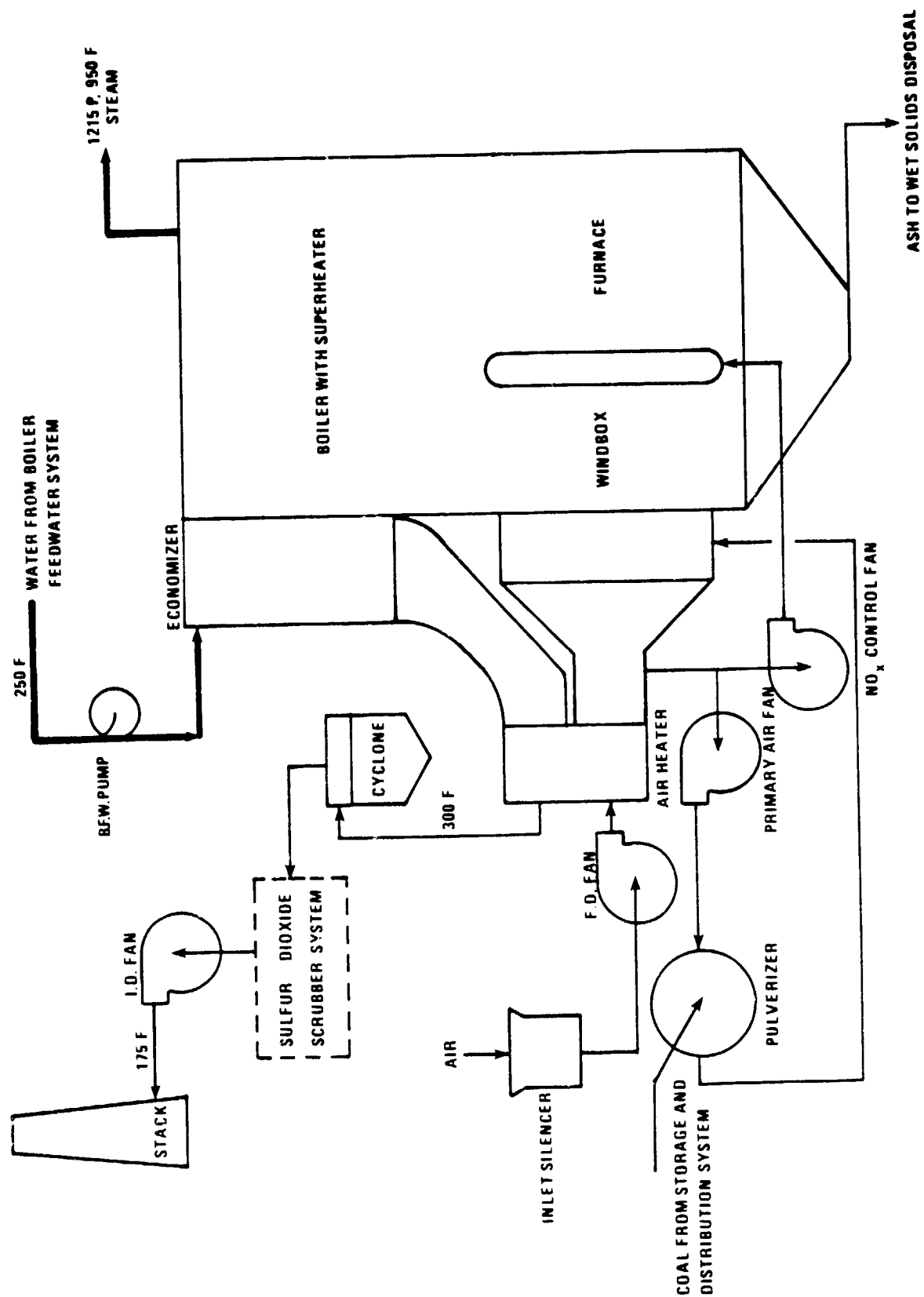


FIGURE IV-30 COAL FIRED, 950F STEAM GENERATOR

TABLE IV-32
COAL FIRED, 950F STEAM GENERATOR
OPERATING PARAMETERS
(500 MILLION BTU/HR)

<u>Stream Number</u>	<u>Flowrate (lb/hr)</u>	<u>Temperature (F)</u>	<u>Pressure (psia)</u>
1	556,000	59	15.1
2	556,000	500	15.0
3	609,500	1000	14.9
4	609,500	700	14.8
5	609,500	300	14.7
6	609,500	175	14.6
7	403,000	250	30.0
8	403,000	255	1365.0
9	399,000	950	1215.0
10	54,500	59	14.7

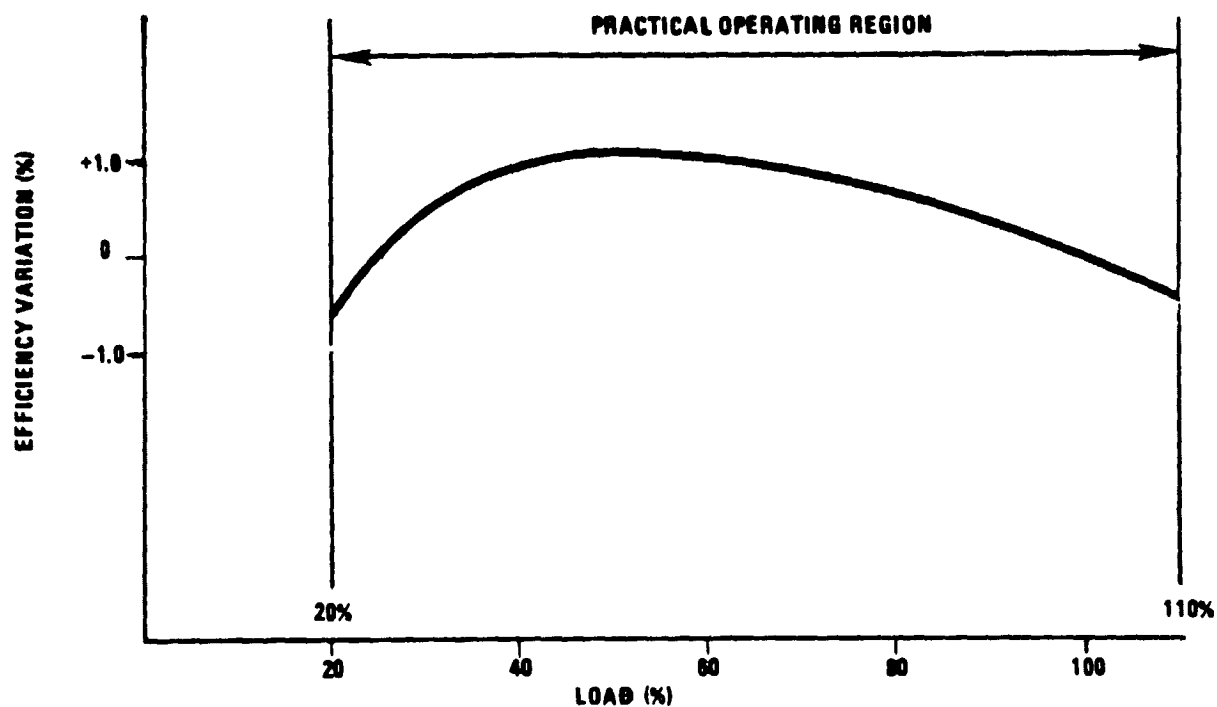


Figure IV-31 VARIATION OF THERMAL EFFICIENCY WITH PERCENT LOAD FOR THE COAL FIRED, 950 F STEAM GENERATOR

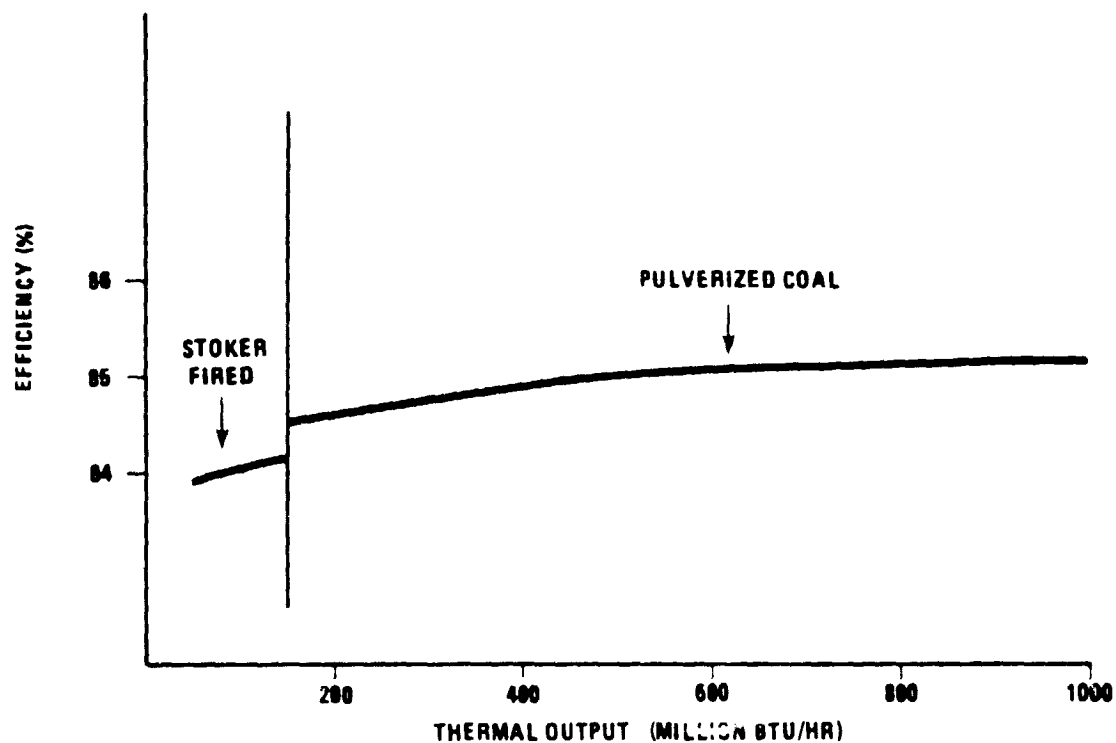


Figure IV-32 VARIATION OF DESIGN POINT EFFICIENCY WITH DESIGN POINT OUTPUT FOR THE COAL FIRED, 950 F STEAM GENERATOR

TABLE IV-33
COAL FIRED, 950F STEAM GENERATOR
ENVIRONMENTAL INTRUSION

<u>Stack Gas Emissions</u>	<u>Predicted Rate (lb/million Btu)</u>
Sulfur Dioxide	1.2
Nitrogen Oxides	0.7
Hydrocarbons	
- Thermal Output	
< 150 million Btu/hr	.046
> 150 million Btu/hr	.014
Carbon Monoxide	
- Thermal Output	
< 150 million Btu/hr	.093
> 150 million Btu/hr	.046
Particulates	0.1
<u>Wastes Discharged</u>	
Water (Blowdown)	6.8
Dry Solids	
- Thermal Output	
< 150 million Btu/hr	1.87
> 150 million Btu/hr	4.98
Wet Solids	
- Thermal Output	
< 150 million Btu/hr	6.23
> 150 million Btu/hr	1.78
<u>Water Required</u> (Exclusive of Boiler Feed Water)	0
<u>Steam Required</u> (50 psig, 300F Condition)	
Fuel Atomizing	0

COST IN MID-1978 DOLLARS

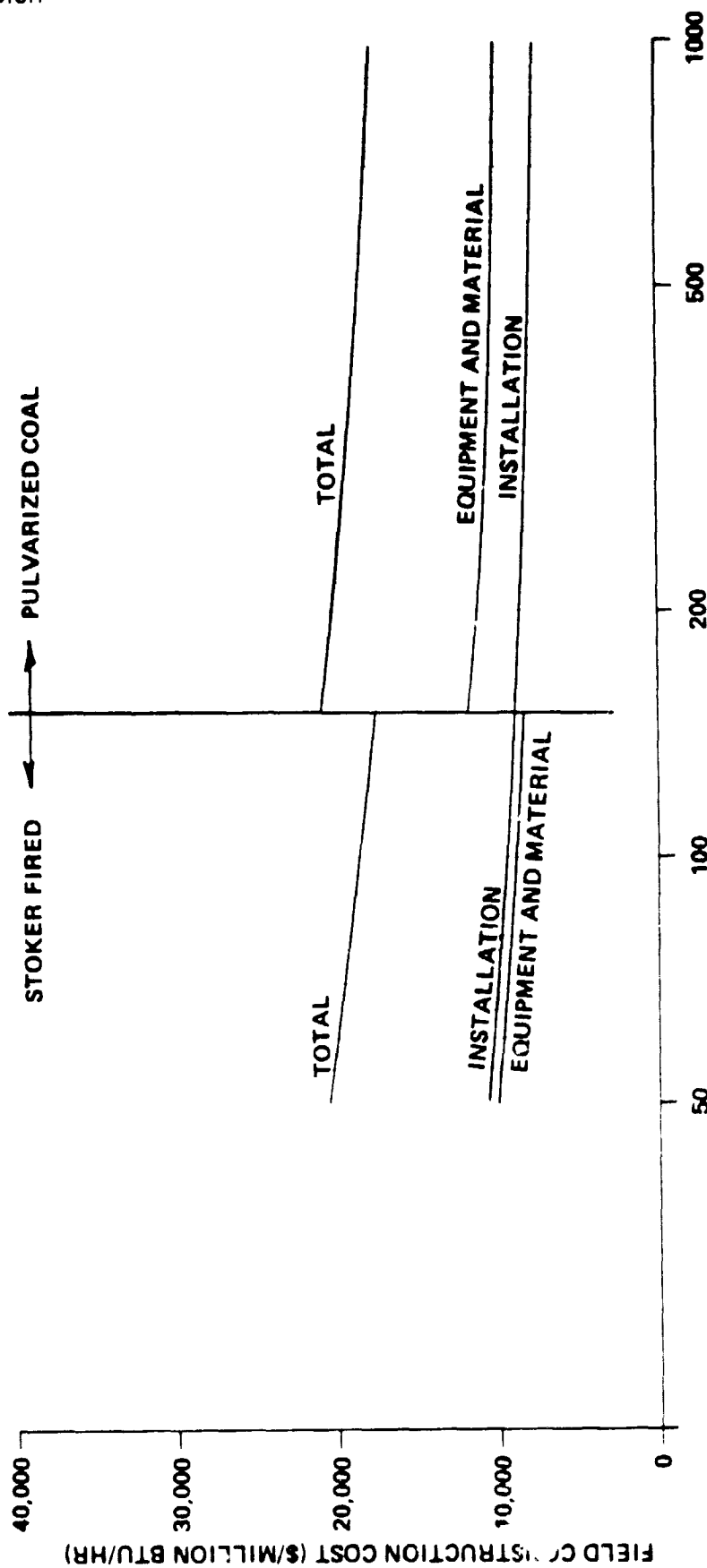


Figure IV-33 VARIATION OF FIELD CONSTRUCTION COST WITH DESIGN THERMAL OUTPUT FOR
COAL FIRED, 950 F STEAM GENERATOR

TABLE IV-34
COAL FIRED, 950F STEAM GENERATOR
FIELD CONSTRUCTION COST
(500 MILLION BTU/HR)

<u>ITEMS</u>	<u>DOLLARS</u>
Equipment	
Furnace, Pulverized Coal Fired (incl. boiler, economizer, and air heater)	4,662,000
Particulate Removal (cyclone)	56,000
Other Equipment	189,000
Civil/Structural	69,000
Piping/Instrumentation	<u>259,000</u>
Total Equipment and Materials	5,235,000
Direct Installation Labor (@ \$14/MH)	2,313,000
Indirects (@ 75% of Direct Labor)	<u>1,735,000</u>
Total Field Construction Cost (Mid-1978 Dollars)	9,283,000 =====

TABLE IV-35
COAL FIRED, 950F STEAM GENERATOR
FIELD CONSTRUCTION COST
(100 MILLION BTU/HR)

<u>ITEMS</u>	<u>DOLLARS</u>
Equipment	
Furnace, Stoker Fired (incl. boiler, economizer, and air heater)	694,000
Particulate Removal (cyclone)	12,000
Other Equipment	108,000
 Civil/Structural	 31,000
Piping/Instrumentation	<u>55,000</u>
Total Equipment and Materials	900,000
 Direct Installation Labor (@ \$14/MH)	 540,000
Indirects (@ 75% of Direct Labor)	<u>405,000</u>
 Total Field Construction Cost (Mid-1978 Dollars)	 1,845,000 =====

CASE 11
COAL FIRED ATMOSPHERIC FLUIDIZED BED, 1050F STEAM GENERATOR

The atmospheric fluidized bed (AFB) steam generator system, shown in Figure IV-34, is an advanced technology heat source in which coal is fired in the presence of limestone at near atmospheric pressure. Sulfur released from the coal is absorbed by the limestone, reducing sulfur dioxide emissions. Heat is transferred to water, the energy conversion system working fluid, by heat transfer surfaces within the bed, in the water-cooled walls, and in the convective space above the bed. The system's design and operating characteristics are as follows.

Characteristics

- AFB Construction - Water-cooled wall construction, Shop fabricated units up to 150 million Btu/hr output; field assembled for larger units
- Partitioned bed for turndown flexibility
- Boiler and superheater heat transfer surfaces in bed; additional superheater surface in freeboard
- Externally located finned-tube economizer
- Forced draft, induced draft, and primary air fans
- Pneumatic coal/limestone feed system
- Reinjection of fly ash collected in cyclone to achieve good combustion efficiency
- Spent bed material cooler for heat recovery

Design Point Performance

- Thermal output - 250 million Btu/hr
- Working fluid conditions
 - Inlet - 15 psig, 250F water
 - Outlet - 1800 psig, 1050F steam
- Thermal efficiency - 84%

Operating Parameters

Table IV-36 gives the flowrate, temperature and pressure of each of the major streams in the system. The stream numbers are

identified on the system schematic diagram. Additional operating parameters are as follows:

- Fluidized bed temperature - 1550F
- Bed superficial velocity - 8 ft/s
- Bed calcium to sulfur ratio - 3:1
- Excess combustion air - 20%
- Heat recovery exhaust gas temperature - 300F

Permissible Range of Operation

Figure IV-35 shows the variation in thermal efficiency over the permissible range of operation.

Effect of Size on Efficiency

Design point efficiency varies only slightly over the range of thermal output considered. The variation shown in Figure IV-36 is due to change in the radiation losses from the boiler.

Auxiliary Power Requirement

Electric power is required for the fans and boiler feedwater pump. The power requirement is 5.9 kWe per million Btu/hr thermal output.

Environmental Intrusion

Table IV-37 gives the stack gas emissions, wastes discharged, and requirements for water and atomizing steam for the heat source system. Data are expressed in pounds of material per million Btu gross energy input to the system (fuel higher heating value). Stack gas emissions for the heat source which includes a particulate removal system were calculated on the basis of fuel specifications defined for this study.

Flexibility and Reliability

The flexibility and reliability characteristics of this advanced technology heat source in relation to current technology cogeneration and non-cogeneration heat sources are as follows.

- Fuel Flexibility. The fluidized bed combustor has greater fuel flexibility than current technology

coal fired systems and will accept a wide range of coals as well as wood and solid wastes as fuel. This heat source was designed for bituminous coal but can be modified to fire other solid fuels. Increased fuel feeding capability would be required for fuels of lower heat content and limestone feed requirements would be modified according to the fuel sulfur content.

- Transition to Coal or Coal Derived Fuels.

(See previous paragraph)

- Operational Flexibility. Load response and turndown characteristics similar to current technology heat sources are achieved by dividing the bed into multiple, individually controlled compartments. The unit may be operated from 20% to 110% of design thermal output with only a small change in efficiency.
- Retrofit to Existing Plants. As is true for current technology coal fired systems, retrofit potential of this heat source is limited because of large space requirements for fuel storage and handling. In this case, the space requirements are further increased by the required limestone storage and handling system.
- Siting Flexibility. The siting requirements are similar to those typical of an industrial plant. Rail access is required for construction and fuel delivery. Water must be available for boiler feed water makeup. However, the system has no special requirements which will influence siting flexibility.
- Potential Reliability. The reliability of the fluidized bed is expected to be similar to that of a current technology coal fired unit. Though the majority of its components are similar to those of a conventional unit, the fluidized bed incorporates a limestone feed system, heat transfer tubing within the combustion zone and a particulate removal cyclone operating at high temperature which are not required by a conventional unit. However, the fluidized bed does not require the coal pulverizer required by a conventional coal fired unit.

Space Requirements

The area and volume requirements for the heat source system are expressed as a function of the system thermal output capacity by the following equations,

$$\text{Area (sq ft)} = 34C$$

$$\text{Volume (cu ft)} = 2520C$$

where C is equal to the system thermal output capacity in million Btu/hr. The area and volume requirements do not include the exhaust stack.

Maintenance and Overhaul

Scheduled maintenance and overhaul frequencies for the heat source system and the associated planned outages are as follows.

	<u>Maintenance</u>	<u>Overhaul</u>
Interval	6 months	36 months
Planned Outage Required	2 week	6 weeks

Capital and Operating Costs

- Capital Cost. Figure IV-37 shows field construction costs versus thermal output for the heat source system. The costs are broken down into equipment and material cost and installation costs. Installation costs include direct installation labor at \$14.00 per manhour plus 75% of direct labor costs for indirect field costs (distributables). Table IV-38 presents the cost breakdown of a system for 250 million Btu/hr thermal output capacity and Table IV-39 presents the cost breakdown of the system for 100 million Btu/hr thermal output capacity.
- Operating and Maintenance. Annual operating and maintenance costs for the system exclusive of fuel costs are estimated at \$380 per million Btu/hr design thermal output capacity of the heat source.

Construction and Installation Period

The construction and installation period required for the heat source is expressed as a function of the system thermal output capacity by the following equation:

$$M = \frac{C}{200} \times 24$$

where M is equal to construction and installation period in months and C is equal to system thermal output capacity in million Btu/hr.

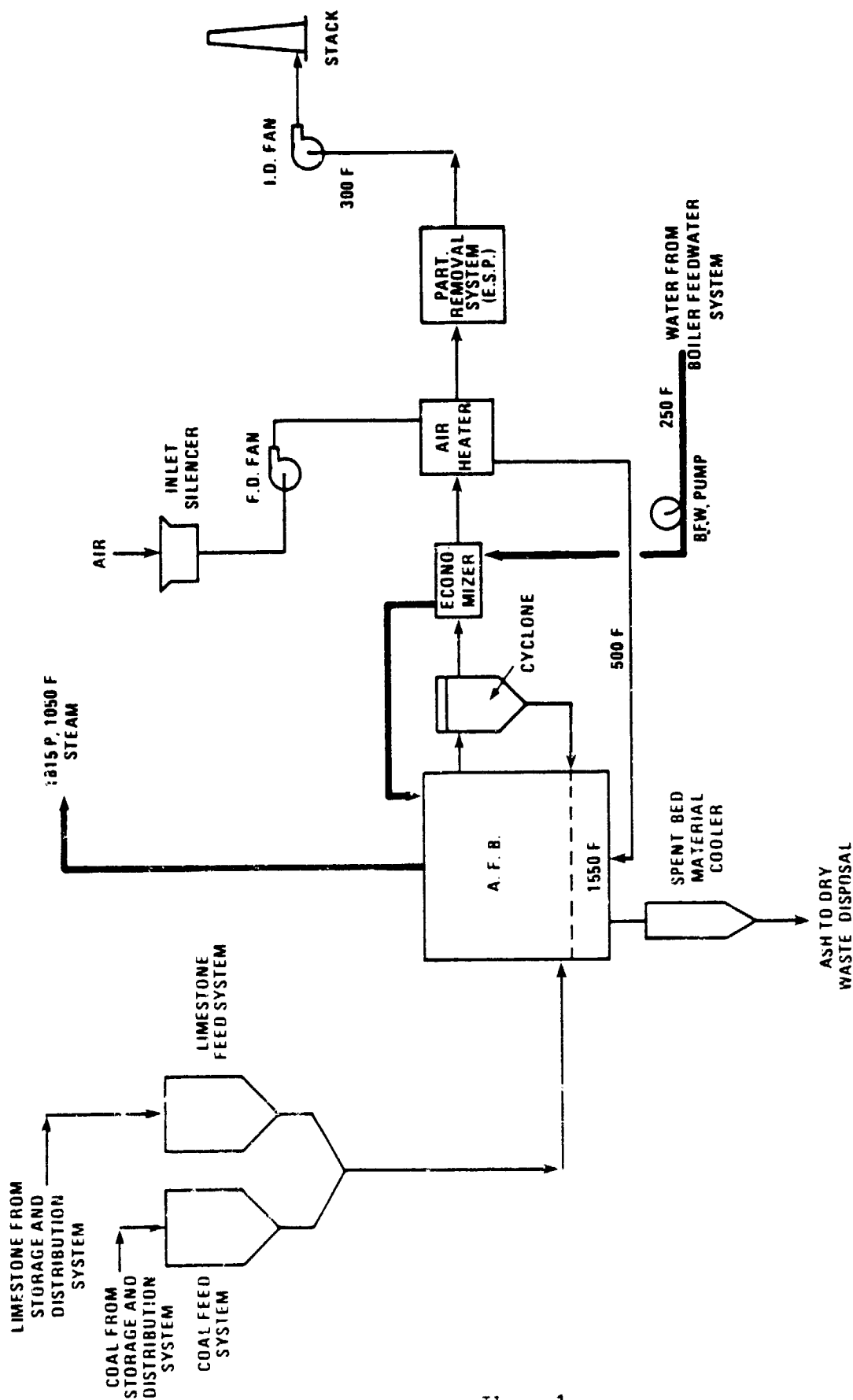


FIGURE IV-34 COAL FIRED ATMOSPHERIC FLUIDIZED BED, 1050F STEAM GENERATOR

TABLE IV-36

COAL FIRED ATMOSPHERIC FLUIDIZED BED, 1050F STEAM GENERATOR
OPERATING PARAMETERS
(250 MILLION BTU/HR)

<u>Stream Number</u>	<u>Flowrate (lb/hr)</u>	<u>Temperature (F)</u>	<u>Pressure (psia)</u>
1	272,000	59	16.7
2	272,000	500	16.5
3	300,000	1550	14.8
4	300,000	1000	14.6
5	300,000	665	14.5
6	300,000	300	14.4
7	195,300	250	30.0
8	195,300	258	2015.0
9	195,300	392	1975.0
10	193,300	1050	1815.0
11	27,500	59	14.7
12	10,500	59	14.7

COST IN MID-1978 DOLLARS

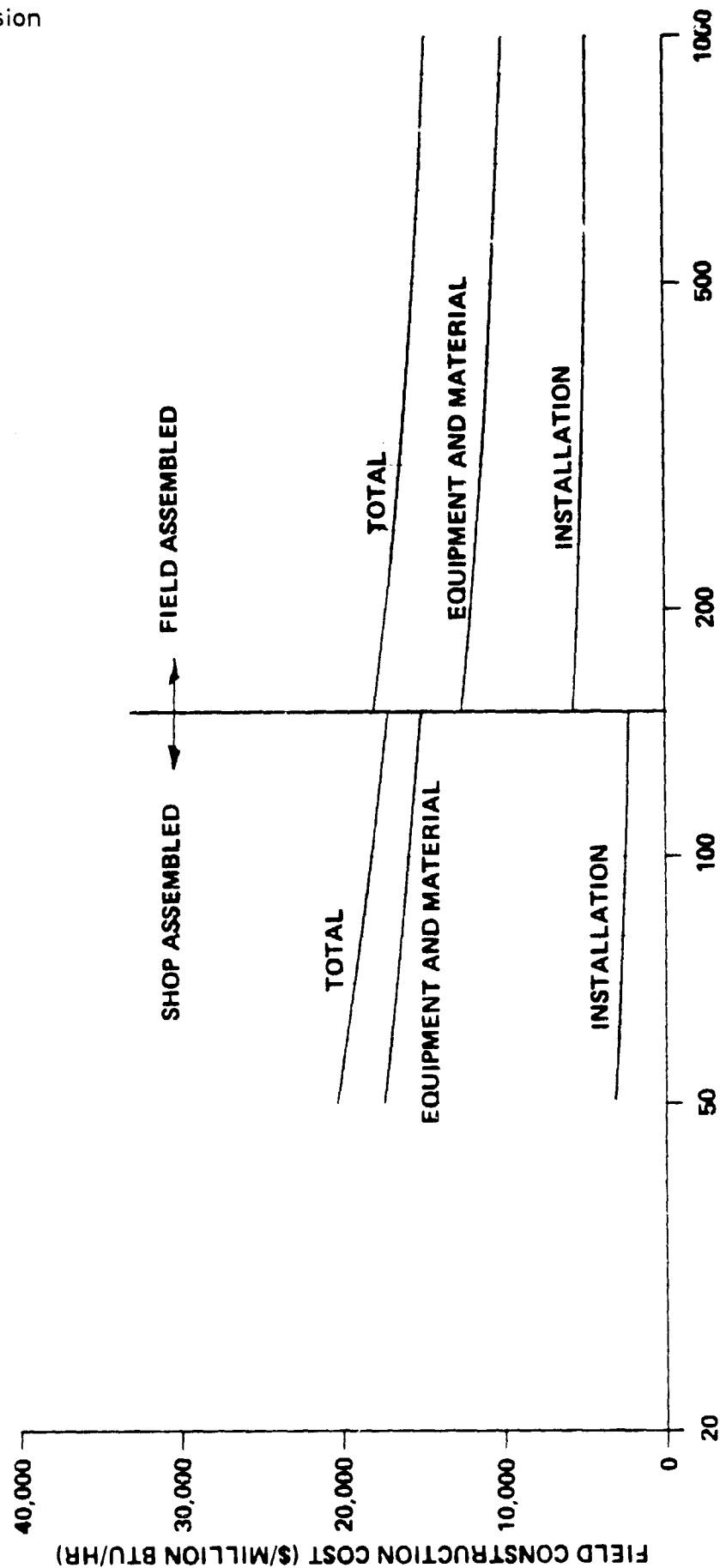


Figure IV-37 VARIATION OF FIELD CONSTRUCTION COST WITH DESIGN THERMAL OUTPUT FOR
COAL FIRED ATMOSPHERIC FLUIDIZED BED, 1050 F STEAM GENERATOR

FCR-1333

TABLE IV-37

COAL FIRED ATMOSPHERIC FLUIDIZED BED, 1050F STEAM GENERATOR
ENVIRONMENTAL INTRUSION

<u>Stack Gas Emissions</u>	<u>Predicted Rate (lb/million Btu)</u>
Sulfur Dioxide	1.2
Nitrogen Oxides	0.2
Hydrocarbons	trace
Carbon Monoxide	0.04
Particulates	0.1
<u>Wastes Discharged</u>	
Water (Blowdown)	6.9
Dry Solids	36.0*
Wet Solids	0
<u>Water Required</u>	
(Exclusive of Boiler Feed Water)	0
<u>Steam Required (50 psig, 300F Condition)</u>	
Fuel Atomizing	0

*Bed spent limestone is not reclaimed.

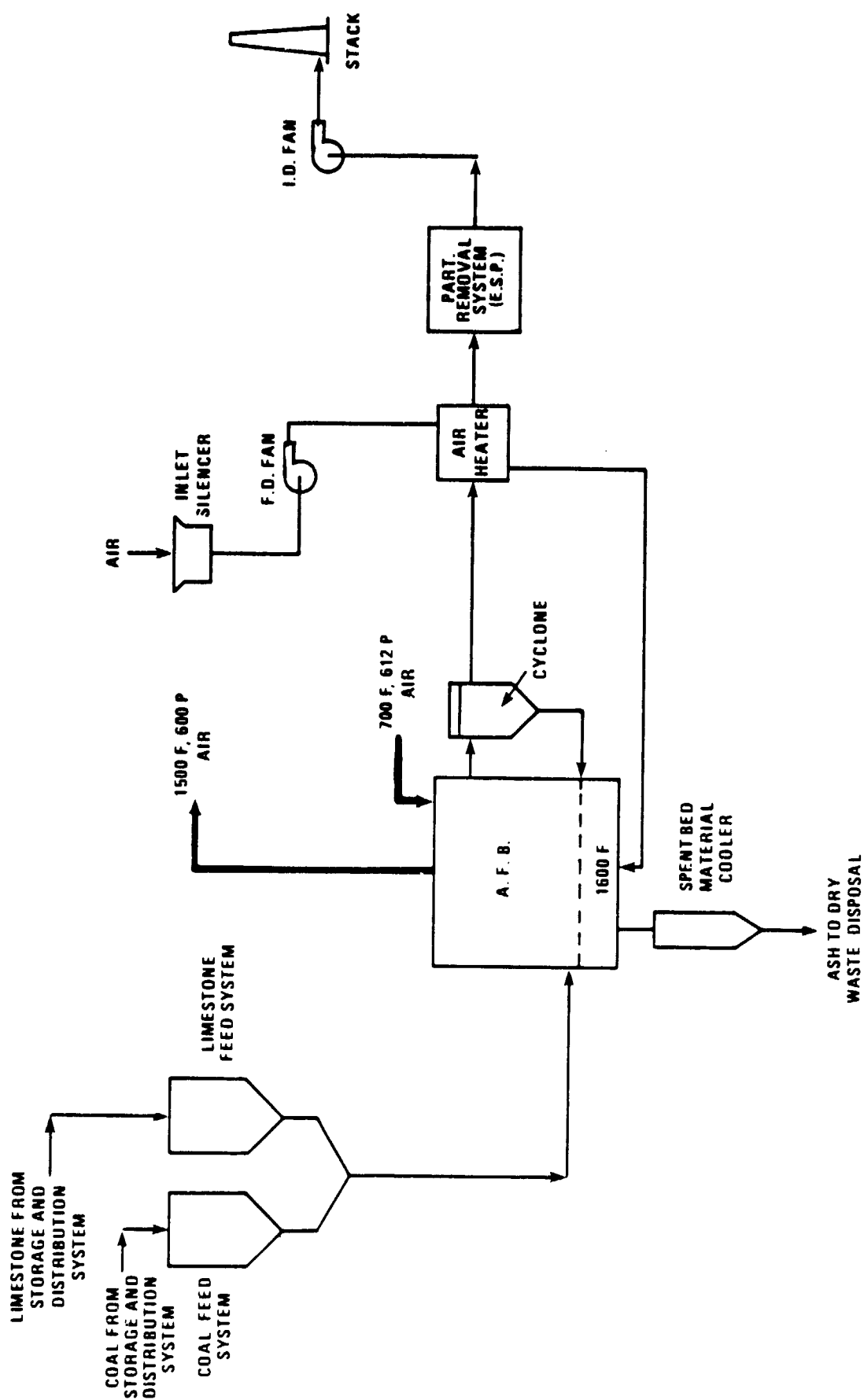


FIGURE IV-38 COAL FIRED ATMOSPHERIC FLUIDIZED BED, 1500°F HOT GAS GENERATOR

TABLE IV-38

COAL FIRED ATMOSPHERIC FLUIDIZED BED, 1050F STEAM GENERATOR

FIELD CONSTRUCTION COST

/ 250 MILLION BTU/HR)

<u>ITEMS</u>	<u>DOLLARS</u>
Equipment	
Furnace, Field Erected (incl. boiler)	1,300,000
Economizer	72,000
Air Heater	250,000
Particulate Removal (cyclone and ESP)	406,000
Other Equipment	612,000
Civil/Structural	170,000
Piping/Instrumentation	<u>90,000</u>
Total Equipment and Materials	2,900,000
Direct Installation Labor (@ \$14/MH)	742,000
Indirects (@ 75% of Direct Labor)	<u>556,000</u>
Total Field Construction Cost (Mid-1978 Dollars)	4,198,000 =====

TABLE IV-39

COAL FIRED ATMOSPHERIC FLUIDIZED BED, 1050F STEAM GENERATOR

FIELD CONSTRUCTION COST

(100 MILLION BTU/HR)

<u>ITEMS</u>	<u>DOLLARS</u>
Equipment	
Furnace, Shop Assembled (incl. boiler)	800,000
Economizer	30,000
Air Heater	105,000
Particulate Removal (cyclone and ESP)	170,000
Other Equipment	347,000
Civil/Structural	108,000
Piping/Instrumentation	<u>30,000</u>
Total Equipment and Materials	1,590,000
Direct Installation Labor (@ \$14/MH)	120,000
Indirects (@ 75% of Direct Labor)	<u>90,000</u>
Total Field Construction Cost (Mid-1978 Dollars)	1,800,000 =====

CASE 12
COAL FIRED ATMOSPHERIC FLUIDIZED BED, 1500F HOT GAS GENERATOR

The atmospheric fluidized bed (AFB) hot gas generator system, shown in Figure IV-38, is an advanced technology heat source in which coal is fired in the presence of limestone at near atmospheric pressure. Sulfur released from the coal is absorbed by the limestone, reducing sulfur dioxide emissions. Heat is transferred to high pressure air, the energy conversion system working fluid, by heat transfer surfaces within the bed and in the convective space above the bed. The system's design and operating characteristics are as follows.

Characteristics

- AFB Construction - Refractory wall construction Shop fabricated units up to 150 million Btu/hr output; field erected for larger units
- Partitioned bed for turndown flexibility
- Super alloy heat exchanger material used in bed
- Externally located tubular air heater
- Forced draft, induced draft, and primary air fans
- Pneumatic coal/limestone feed system
- Reinjection of fly ash collected in cyclone to achieve good combustion efficiency
- Spent bed material cooler for heat recovery

Design Point Performance

- Thermal output - 250 million Btu/hr
- Working fluid conditions
 - Inlet - 700F, 612 psia air
 - Outlet - 1500F, 600 psia air
- Thermal efficiency - 84%

Operating Parameters

Table IV-40 gives the flowrate, temperature and pressure of each of the major streams in the system. The stream numbers are

identified on the system schematic diagram. Additional operating parameters are as follows:

- Fluidized bed temperature - 1600F
- Bed superficial velocity - 8 ft/s
- Bed calcium to sulfur ratio - 4:1
- Excess combustion air - 20%
- Heat recovery exhaust gas temperature - 300F

Permissible Range of Operation

The permissible range of operation and variation in thermal efficiency over that range is the same for this system as for the coal fired AFB, 1050F steam generator as shown in Figure IV-35.

Effect of Capacity on Efficiency

The variation of design point thermal efficiency with capacity is the same for this system as for the coal fired AFB, 1050F steam generator as shown in Figure IV-36.

Auxiliary Power Requirement

Electric power is required for the system fans. The power requirement is 3.9 kWe per million Btu/hr thermal output.

Environmental Intrusion

Table IV-41 gives the stack gas emissions, wastes discharged, and requirements for water and atomizing steam for the heat source system. Data are expressed in pounds of material per million Btu gross energy input to the system (fuel higher heating value). Stack gas emissions for the heat source which includes a particulate removal system were calculated on the basis of fuel specifications defined for this study.

Flexibility and Reliability

The flexibility and reliability characteristics of this advanced technology heat source in relation to current technology cogeneration and non-cogeneration heat sources are as follows.

- Fuel Flexibility. The fluidized bed combustor has greater fuel flexibility than current technology coal fired systems and will accept a wide range of coals as well as wood and solid wastes as fuel.

This heat source was designed for bituminous coal but can be modified to fire other solid fuels. Increased fuel feeding capability would be required for fuels of lower heat content and limestone feed requirements would be modified according to the fuel sulfur content.

- Transition to Coal or Coal Derived Fuels.

(See previous paragraph)

- Operational Flexibility. Load response and turndown characteristics similar to current technology heat sources are achieved by dividing the bed into multiple, individually controlled compartments. The unit may be operated from 20% to 110% of design thermal output with only a small change in efficiency.
- Retrofit to Existing Plants. As is true for current technology coal fired systems, retrofit potential of this heat source is limited because of large space requirements for fuel storage and handling. In this case, the space requirements are further increased by the required limestone storage and handling system.
- Siting Flexibility. The siting requirements are similar to those typical of an industrial plant. Rail access is required for construction and fuel delivery. However, the system has no special requirements which will influence siting flexibility.
- Potential Reliability. The reliability of the fluidized bed is expected to be similar to that of a current technology coal fired unit. Though the majority of its components are similar to those of a conventional unit, the fluidized bed incorporates a limestone feed system, heat transfer tubing within the combustion zone and a particulate removal cyclone operating at high temperature which are not required by a conventional unit. However, the fluidized bed does not require the coal pulverizer which is required by a conventional coal fired unit.

Space Requirements

The area and volume requirements for the heat source system are expressed as a function of the system thermal output capacity by the following equations,

$$\text{Area (sq ft)} = 34C$$

$$\text{Volume (cu ft)} = 2520C$$

where C is equal to the system thermal output capacity in million Btu/hr. The area and volume requirements do not include the exhaust stack.

Maintenance and Overhaul

Scheduled maintenance and overhaul frequencies for the heat source system and the associated planned outages are as follows.

	<u>Maintenance</u>	<u>Overhaul</u>
Interval	6 months	36 months
Planned Outage Required	2 weeks	5 weeks

Capital and Operating Costs

- Capital Cost. Figure IV-39 shows field construction costs versus thermal output for the heat source system. The costs are broken down into equipment and material cost and installation costs. Installation costs include direct installation labor at \$14.00 per manhour plus 75% of direct labor costs for indirect field costs (distributables). Table IV-42 presents the cost breakdown of a system for 250 million Btu/hr thermal output capacity and Table IV-43 presents the cost breakdown of a system for 100 million Btu/hr thermal output capacity.
- Operating and Maintenance. Annual operating and maintenance costs for the system exclusive of fuel costs are estimated at \$380 per million Btu/hr design thermal output capacity of the heat source.

Construction and Installation Period

The construction and installation period required for the heat source is expressed as a function of the system thermal output capacity by the following equation:

$$M = \frac{C}{200} \times 27$$

where M is equal to construction and installation period in months and C is equal to system thermal output capacity in million Btu/hr.

COST IN MID-1978 DOLLARS

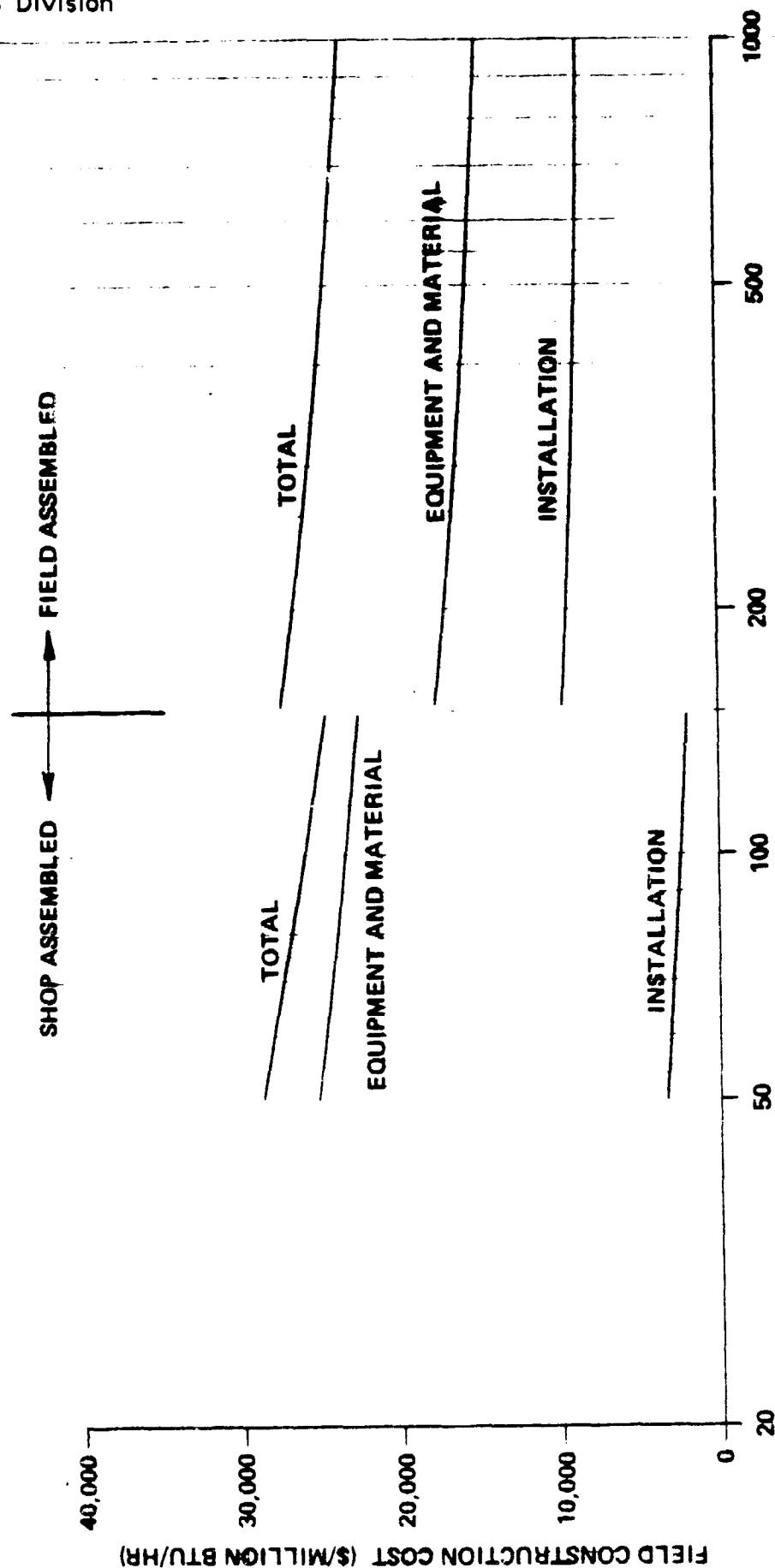


Figure IV-39 VARIATION OF FIELD CONSTRUCTION COST WITH DESIGN THERMAL OUTPUT FOR
COAL FIRED ATMOSPHERIC FLUIDIZED BED, 1500 F HOT GAS GENERATOR

TABLE IV-40

COAL FIRED ATMOSPHERIC FLUIDIZED BED, 1500F HOT GAS GENERATOR
OPERATING PARAMETERS
(250 MILLION BTU/HR)

<u>Stream Number</u>	<u>Flowrate (lb/hr)</u>	<u>Temperature (F)</u>	<u>Pressure (psia)</u>
1	274,000	59	16.7
2	274,000	737	16.5
3	303,000	1600	14.8
4	303,000	914	14.6
5	303,000	300	14.5
6	1,176,000	700	612.0
7	1,176,000	1500	600.0
8	27,500	59	14.7
9	14,000	59	14.7

TABLE IV-41

COAL FIRED ATMOSPHERIC FLUIDIZED BED, 1500F HOT GAS GENERATOR
ENVIRONMENTAL INTRUSION

<u>Stack Gas Emissions</u>	<u>Predicted Rate (lb/million Btu)</u>
Sulfur Dioxide	1.2
Nitrogen Oxides	0.2
Hydrocarbons	trace
Carbon Monoxide	0.04
Particulates	0.1
 <u>Wastes Discharged</u>	
Water (Blowdown)	0
Dry Solids	42.0*
Wet Solids	0
 <u>Water Required</u>	
(Exclusive of Boiler Feed Water)	0
 <u>Steam Required (50 psig, 300F Condition)</u>	
Fuel Atomizing	0

*Bed spent limestone is not reclaimed.

TABLE IV-42

COAL FIRED ATMOSPHERIC FLUIDIZED BED, 1500F HOT GAS GENERATOR

FIELD CONSTRUCTION COST

(250 MILLION BTU/HR)

<u>ITEMS</u>	<u>DOLLARS</u>
Equipment	
Furnace, Field Erected	2,750,000
Air Heater	326,000
Particulate Removal (cyclone and ESP)	406,000
Other Equipment	509,000
 Civil/Structural	 170,000
Piping/Instrumentation	<u>66,000</u>
Total Equipment and Materials	4,227,000
 Direct Installation Labor (@ \$14/MH)	 1,350,000
Indirects (@ 75% of Direct Labor)	<u>1,012,000</u>
 Total Field Construction Cost	 6,589,000
(Mid-1978 Dollars)	=====

TABLE IV-43

COAL FIRED ATMOSPHERIC FLUIDIZED BED, 1500F HOT GAS GENERATOR
FIELD CONSTRUCTION COST
(100 MILLION BTU/HR)

<u>ITEMS</u>	<u>DOLLARS</u>
Equipment	
Furnace, Shop Assembled	1,660,000
Air Heater	137,000
Particulate Removal (Cyclone and ESP)	170,000
Other Equipment	273,000
 Civil/Structural	 108,000
Piping/Instrumentation	<u>22,000</u>
Total Equipment and Materials	2,370,000
 Direct Installation Labor (@ \$14/MH)	 120,000
Indirects (@ 75% of Direct Labor)	<u>90,000</u>
 Total Field Construction Cost (Mid-1978 Dollars)	 2,580,000 =====

CASE 13
COAL FIRED PRESSURIZED FLUIDIZED BED, 1600F HOT GAS GENERATOR

The pressurized fluidized bed (PFB) hot gas generator system, shown in Figure IV-40, is an advanced technology heat source in which coal is fired in the presence of dolomite at high pressure. Sulfur released from the coal is absorbed by the dolomite reducing sulfur dioxide emissions. Heat is transferred to high pressure air in tubes within the fluidized bed combustion zone. This air is combined with the PFB combustion products which have passed through a hot gas cleanup system* to form a hot gas stream which is supplied to the energy conversion process. The system requires a hot gas cleanup system to make the gas suitable for the process. The design and operating characteristics of the heat source are as follows.

Characteristics

- PFB construction - Shop fabricated in units up to 250 million Btu/hr; multiple units used for larger systems
- Refractory lined carbon steel furnace
- Finned tube, high temperature alloy heat exchanger within fluidized bed
- Pneumatic coal/dolomite feed system
- Reinjection of fly ash collected in cyclone to achieve good combustion efficiency
- Spent bed material cooler for heat recovery

Design Point Performance

- Thermal output - 250 million Btu/hr
- Working fluid conditions
 - Inlet - 220 psig, 740F air
 - Outlet - 200 psig, 1600F air
- Thermal efficiency - 98%

*Hot gas cleanup system is not included as part of this heat source. It is a balance of plant system.

Operating Parameters

Table IV-44 gives the flowrate, temperature and pressure for each of the major streams in the system. The stream numbers are identified on the system schematic diagram. Additional operating parameters are as follows.

- Fluidized bed temperature - 1650F
- Bed superficial velocity - 2.7 ft/s
- Bed calcium to sulfur ratio - 1.5:1
- Excess combustion air - 30%

Permissible Range of Operation

Figure IV-41 shows the variation in thermal efficiency over the permissible range of operation.

Effect of Capacity on Efficiency

As shown in Figure IV-42, design point efficiency varies only slightly over the range of 50 to 250 million Btu/hr thermal output. The variation is due to changes in the radiation losses from the furnace. The thermal efficiency is constant for larger systems because multiple 250 million Btu/hr modules are used.

Auxiliary Power Requirement

Electric power is required for the fuel injection system. The power requirement is 0.55 kWe per million Btu/hr thermal output.

Environmental Intrusion

Table IV-45 gives the combustion product gas emissions, wastes discharged, and requirements for water and atomizing steam for the heat source system. Data are expressed in pounds of material per million Btu gross energy input to the system (fuel higher heating value). Combustion product gas emissions which were calculated on the basis of fuel specifications defined for this study include the effects of incorporating a hot gas cleanup system.

Flexibility and Reliability

The flexibility and reliability characteristics of this advanced technology heat source in relation to current technology cogeneration and non-cogeneration heat sources are as follows.

- Fuel Flexibility. The fluidized bed combustor has greater fuel flexibility than current technology coal fired systems and will accept a wide range of coals as well as wood and solid wastes as fuel. This heat source was designed for bituminous coal but can be modified to fire other solid fuels. Increased fuel feeding capability would be required for fuels of lower heat content and dolomite feed requirements would be modified according to the fuel sulfur content.
- Transition to Coal or Coal Derived Fuels.
(See previous paragraph)
- Operational Flexibility. The unit may be operated from 30% to 110% of design thermal output with only a small change in efficiency. During part load operation bed temperature and fluidizing velocity remain constant for good combustion efficiency and sulfur capture, and airflow through the heat exchanger is reduced.
- Retrofit to Existing Plants. As is true for current technology coal fired systems, retrofit potential of this heat source is limited because of large space requirements for fuel storage and handling. In this case, the space requirements are further increased by the required dolomite storage and handling system.
- Siting Flexibility. The siting requirements are similar to those typical of an industrial plant. Rail access is required for construction and fuel delivery. However, the system has no special requirements which will influence siting flexibility.
- Potential Reliability. The reliability of the pressurized fluidized bed is expected to be similar to that of a conventional coal fired furnace because the two systems are similar in complexity. The fluidized bed requires pressurized coal and dolomite feed systems but does not incorporate a coal pulverizer or combustion air fans. The reliability of the fluidized bed system is further enhanced for large capacity systems by the use of multiple fluidized bed units.

Space Requirements

The area and volume requirements for the heat source system are expressed as a function of the system thermal output capacity by the following equations,

$$\text{Area (sq ft)} = 7C$$

$$\text{Volume (cu ft)} = 394C$$

where C is equal to the system thermal output capacity in million Btu/hr. The area and volume requirements do not include the exhaust stack.

Maintenance and Overhaul

Scheduled maintenance and overhaul frequencies for the heat source system and the associated planned outages are as follows.

	<u>Maintenance</u>	<u>Overhaul</u>
Interval	6 months	36 months
Planned Outage Required	2 weeks	6 weeks

Capital and Operating Costs

- Capital Cost. Figure IV-43 shows field construction costs versus thermal output for the heat source system. The costs are broken down into equipment and material cost and installation costs. Installation costs include direct installation labor at \$14.00 per manhour plus 75% of direct labor costs for indirect field costs (distributables). Table IV-46 presents the cost breakdown of a system for 250 million Btu/hr thermal output capacity.
- Operating and Maintenance. Annual operating and maintenance costs for the system exclusive of fuel costs are estimated at \$350 per million Btu/hr design thermal output capacity of the heat source.

Construction and Installation Period

The construction and installation period required for the heat source is expressed as a function of the system thermal output capacity by the following equation:

$$M = \frac{C}{200} \times 27$$

where M is equal to construction and installation period in months and C is equal to system thermal output capacity in million Btu/hr.

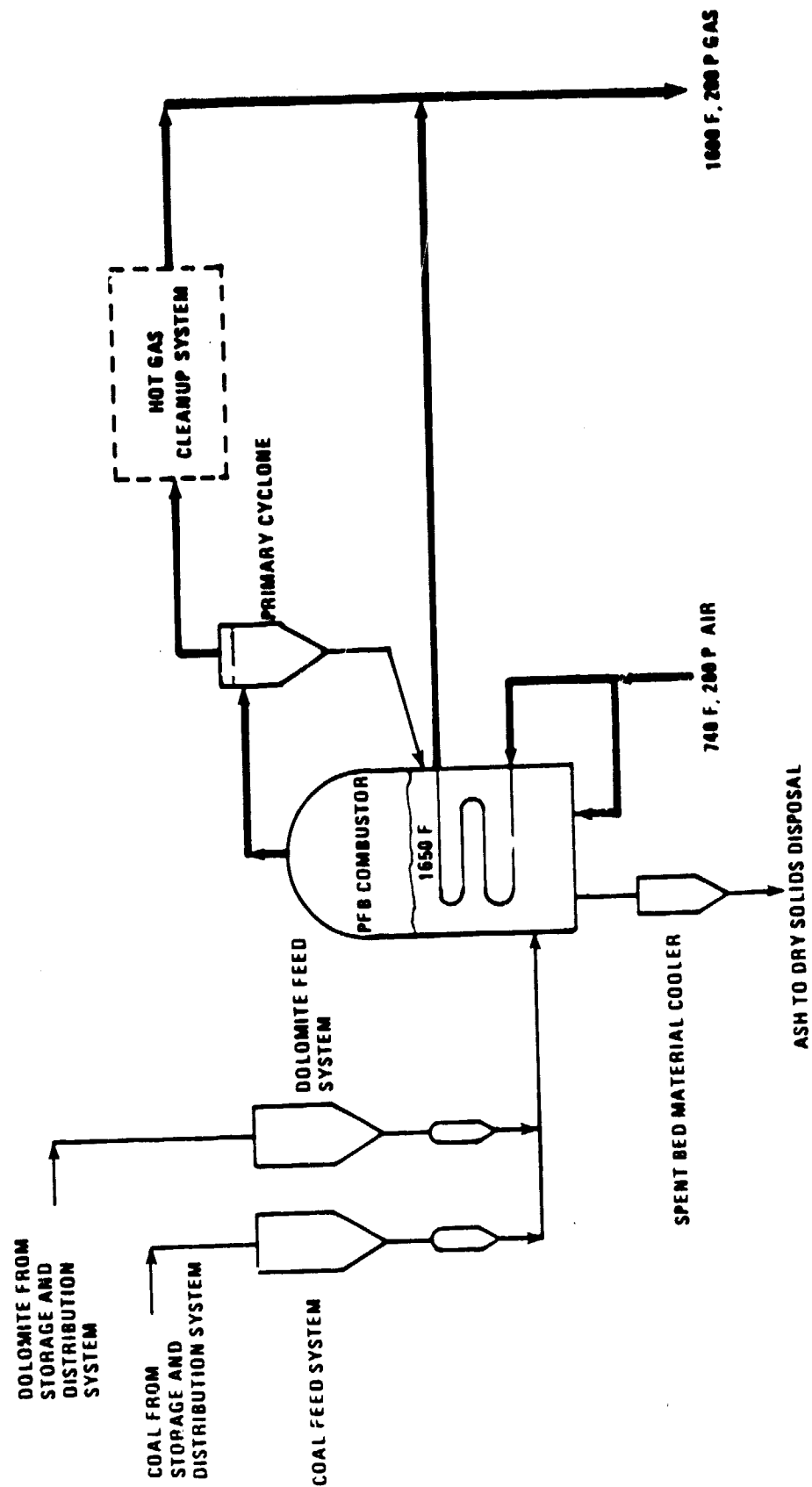


FIGURE IV-40 COAL FIRED PRESSURIZED FLUIDIZED BED, 1600F HOT GAS GENERATOR

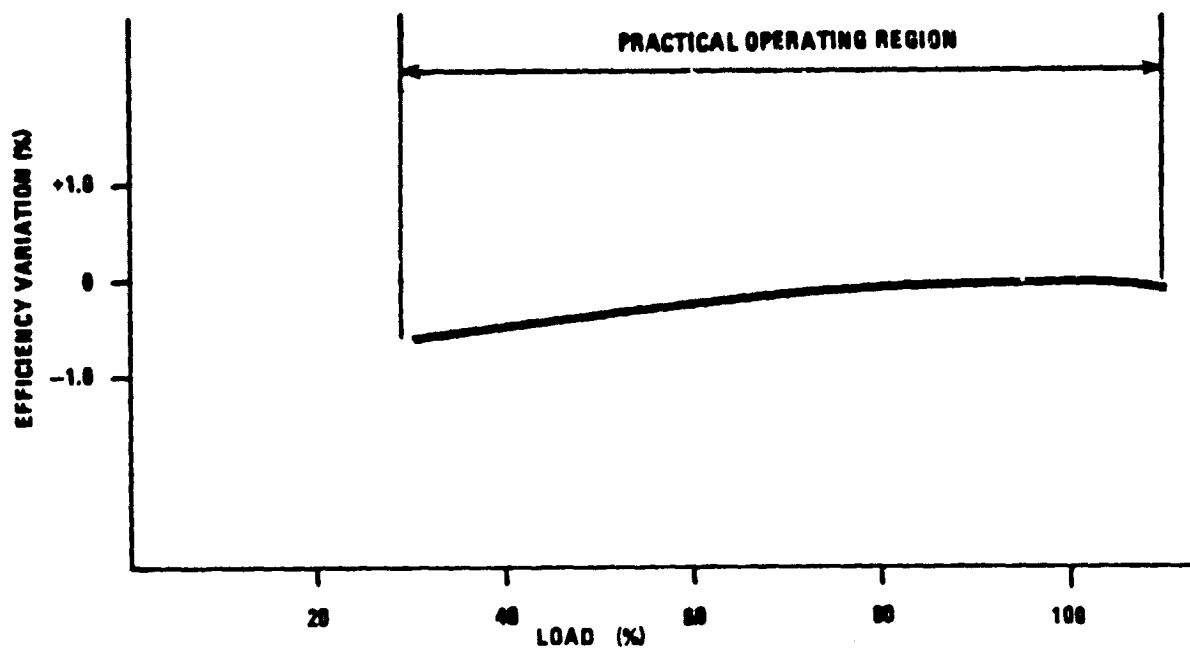


Figure IV-41 VARIATION OF THERMAL EFFICIENCY WITH PERCENT LOAD FOR THE COAL FIRED PFB, 1600 F HOT GAS GENERATOR

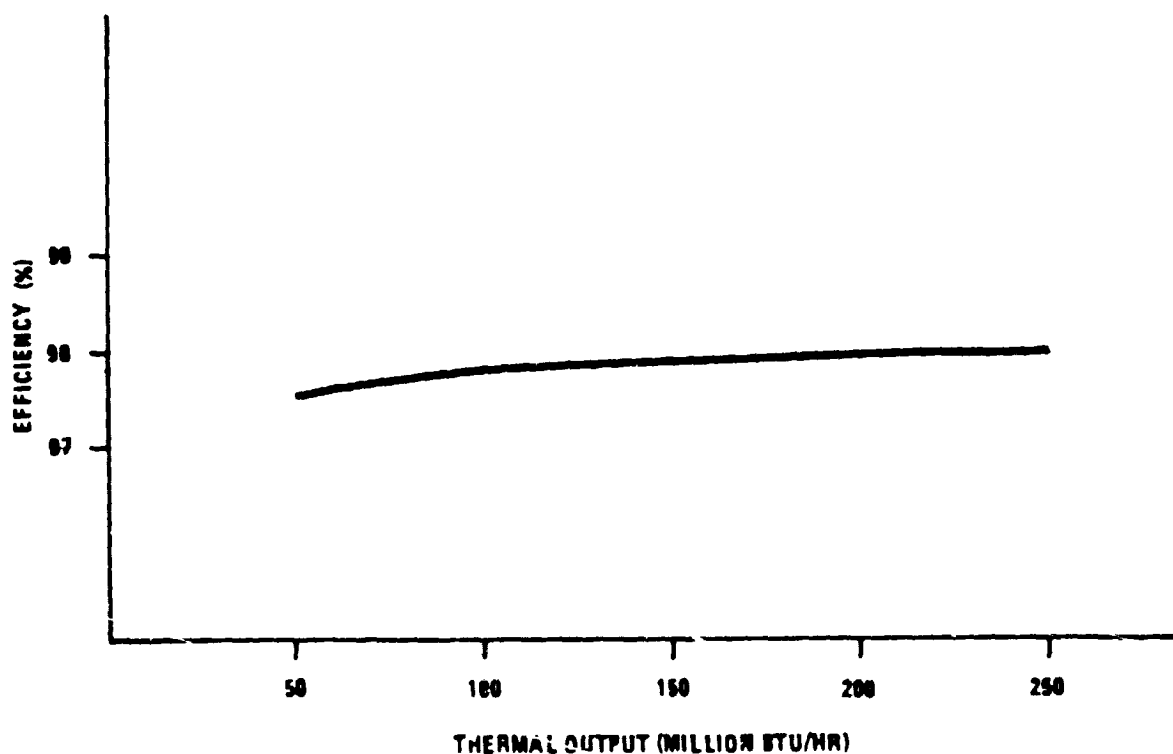


Figure IV-42 VARIATION OF DESIGN POINT THERMAL EFFICIENCY WITH DESIGN POINT OUTPUT FOR THE COAL FIRED PFB, 1600 F HOT GAS GENERATOR

TABLE IV-44

COAL FIRED PRESSURIZED FLUIDIZED BED, 1600F HOT GAS GENERATOR

OPERATING PARAMETERS

(250 MILLION BTU/HR)

<u>Stream Number</u>	<u>Flowrate (lb/hr)</u>	<u>Temperature (F)</u>	<u>Pressure (psia)</u>
1	954,000	740	220.0
2	254,000	740	220.0
3	278,000	1650	210.0
4	278,000	1640	200.0
5	700,000	740	220.0
6	700,000	1575	200.0
7	978,000	1600	200.0
8	23,600	59	14.7
9	8,200	59	14.7

COST IN MID-1978 DOLLARS

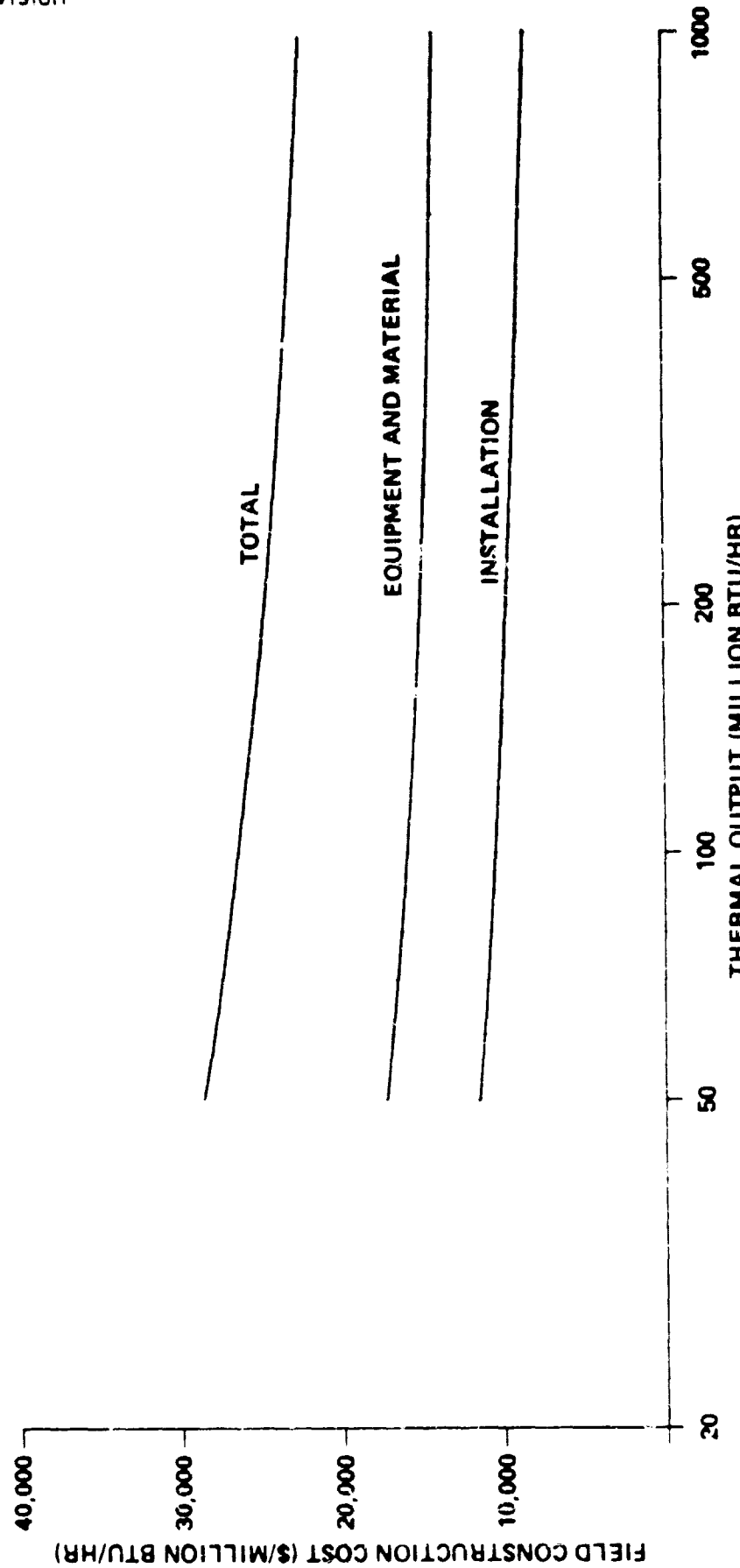


Figure IV-43 VARIATION OF FIELD CONSTRUCTION COST WITH DESIGN THERMAL OUTPUT FOR COAL FIRED PRESSURIZED FLUIDIZED BED, 1600 F HOT GAS GENERATOR

TABLE IV-45

COAL FIRED PRESSURIZED FLUIDIZED BED, 1600F HOT GAS GENERATOR
ENVIRONMENTAL INTRUSION

<u>Combustion Product Gas Emissions</u>	<u>Predicted Rate (lb/million Btu)</u>
Sulfur Dioxide	1.2
Nitrogen Oxides	0.2
Hydrocarbons	trace
Carbon Monoxide	0.04
Particulates	0.001
<u>Wastes Discharged</u>	
Water (Blowdown)	0
Dry Solids	33.0*
Wet Solids	0
<u>Water Required</u>	
(Exclusive of Boiler Feed Water)	0
<u>Steam Required (50 psig, 300F Condition)</u>	
Fuel Atomizing	0

*Bed spent dolomite is not reclaimed.

TABLE IV-46

COAL FIRED PRESSURIZED BED, 600F HOT GAS GENERATOR

FIELD CONSTRUCTION COST

(250 MILLION BTU/HR)

<u>ITEMS</u>	<u>DOLLARS</u>
Equipment	
Furnace	2,100,000
Particulate Removal (cyclone)	53,000
Other Equipment	1,198,000
Civil/Structural	84,000
Piping/Instrumentation	<u>335,000</u>
Total Equipment and Materials	3,770,000
Direct Installation Labor (@ \$14/MH)	1,340,000
Indirects (@ 75% of Direct Labor)	<u>1,005,000</u>
Total Field Construction Cost (Mid-1978 Dollars)	6,115,000 =====

CASE 14
INDUSTRIAL WASTE HEAT, 950F STEAM GENERATOR

The waste heat boiler system, shown in Figure IV-44, is a current technology heat source which recovers the heat from hot gas produced by an industrial process to generate high pressure, 950F steam and low pressure, 300F steam. The design and operating characteristics of the system are as follows.

Characteristics

- Horizontal gas flow unit with top supported vertical tubes
- Finned tubes for superheater, boilers, and economizers
- Bypass stack and associated damper
- Induced draft fan compensates for system pressure loss
- Separate feed water pumps for high and low pressure steam systems
- Reducing valve for low pressure steam

Design Point Performance

- Thermal output - 250 million Btu/hr
- Working fluid conditions
 - Inlet - 10 psig, 240F water
 - Outlet - 1200 psig, 950F steam (82% of output)
 - 50 psig, 300F steam (18% of output)
- Thermal efficiency - 53%

Operating Parameters

Table IV-47 gives the flowrate, temperature and pressure of each of the major streams in the system. The stream numbers are identified on the system schematic diagram. Other operating parameters are as follows:

- Industrial waste gas - 1000F combustion products from natural gas burned with 10% excess air; low particulate loading. (395.6 Btu/lb of total heat,

equal to sensible heat, ref. 59F, plus latent heat of moisture)

- Minimum temperature difference across heat exchanger - 30F

Permissible Range of Operation

The part power performance of the system is dependent on the industrial process which supplies the hot gas stream.

Effect of Capacity on Efficiency

The system design point efficiency is independent of system thermal output because gas inlet and outlet conditions are constant and variation in radiation loss is negligible.

Auxiliary Power Requirement

Electric power is required for the induced draft fan and boiler feed water pumps. The power requirement is 3.4 kWe per million Btu/hr.

Environmental Intrusion

Table IV-48 gives the wastes discharged and requirements of water and atomizing steam for the heat source system. Data are expressed in pounds of material per million Btu gross energy input to the system. Stack gas emissions are dependent on the process hot gas source and are not effected by the waste heat boiler.

Flexibility and Reliability

This current technology heat source for non-cogeneration applications represents a baseline system to which the advanced technology cogeneration heat sources will be compared. Its characteristics are as follows.

- Fuel Flexibility.
(Not applicable)
- Transition to Coal or Coal Derived Fuel.
(Not applicable)
- Operational Flexibility. The unit may be operated from 20% to 110% of design thermal output. The

plant power performance is dependent on the industrial process which supplies the hot gas stream.

- Retrofit to Existing Plants. Retrofit potential is good for process plants exhausting clean hot gas. Space requirements are low and the system does not have special operational or safety problems.
- Retrofit of Technology Advancements. No applicable technology advancements have been identified.
- Siting Flexibility. The siting requirements are similar to those typical of an industrial plant. Rail access is required for construction. Water must be available for boiler feed water makeup. However, the system has no special requirements which will influence siting flexibility.
- Potential Reliability. Reliability has been shown historically to be high. Multiple units can be used to increase reliability without large cost penalties because capital and operating costs are relatively insensitive to unit size.

Space Requirements

The area and volume requirements for the heat source system are expressed as a function of the system thermal output capacity by the following equations,

$$\text{Area (sq ft)} = 25C$$

$$\text{Volume (cu ft)} = 1400C$$

where C is equal to the system thermal output capacity in million Btu/hr. The area and volume requirements do not include the exhaust stack.

Maintenance and Overhaul

Scheduled maintenance and overhaul frequencies for the heat source system and the associated planned outages are as follows.

	<u>Maintenance</u>	<u>Overhaul</u>
Interval	12 months	60 months
Planned Outage Required	1 week	4 weeks

Capital and Operating Costs

- Capital Cost. Figure IV-45 shows field construction costs versus thermal output for the heat source system. The costs are broken down into equipment and material cost and installation costs. Installation costs include direct installation labor at \$14.00 per manhour plus 75% of direct labor costs for indirect field costs (distributables). Table IV-49 presents the cost breakdown of a system for 250 million Btu/hr thermal output capacity.
- Operating and Maintenance. Annual operating and maintenance costs for the system exclusive of fuel costs are estimated at \$175 per million Btu/hr design thermal output capacity of the heat source.

Construction and Installation Period

The construction and installation period required for the heat source is expressed as a function of the system thermal output capacity by the following equation:

$$M = \frac{C}{200} \times 19$$

where M is equal to construction and installation period in months and C is equal to system thermal output capacity in million Btu/hr.

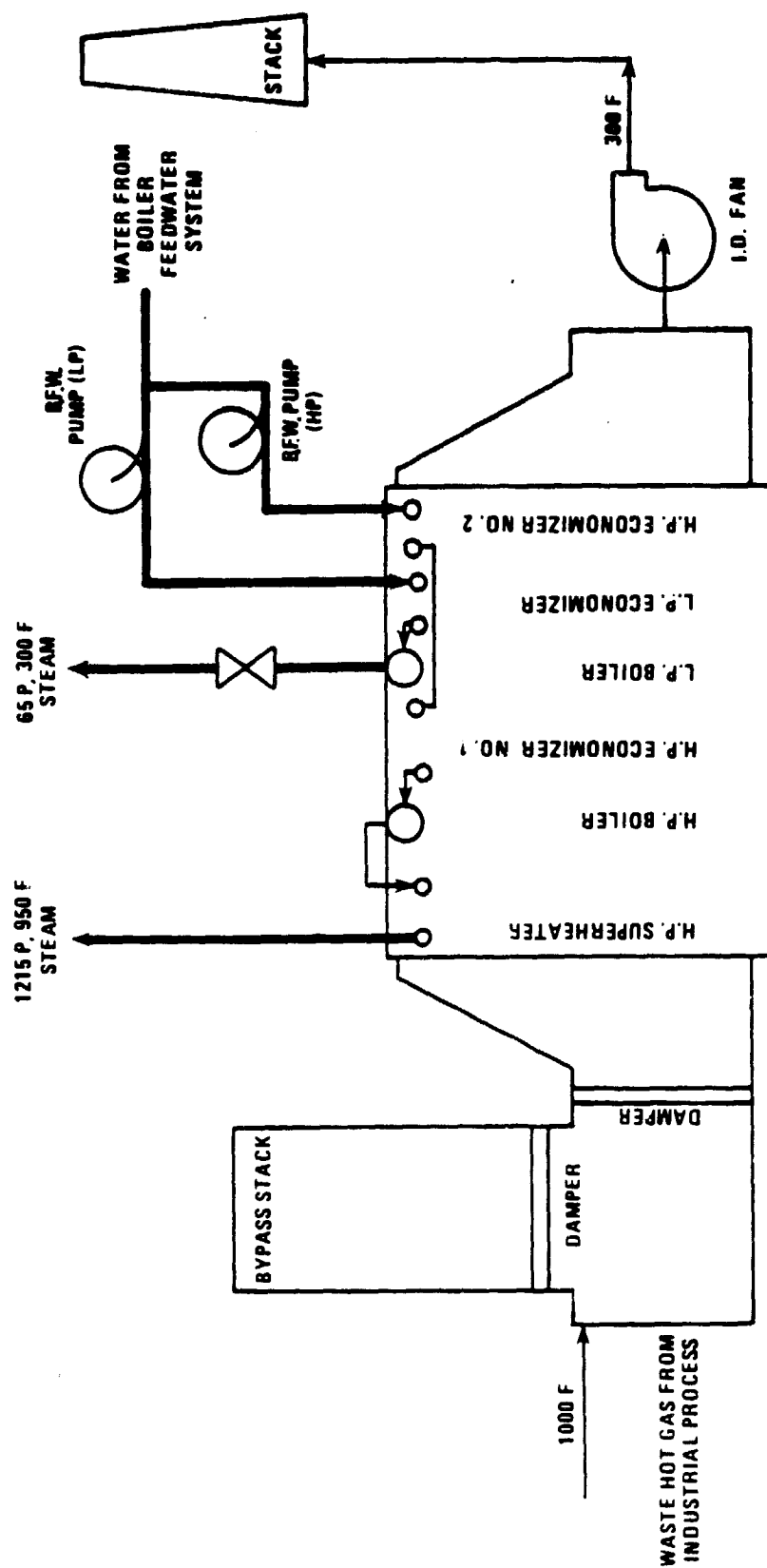


FIGURE IV-44 INDUSTRIAL WASTE HEAT RECOVERY, 950F STEAM GENERATOR

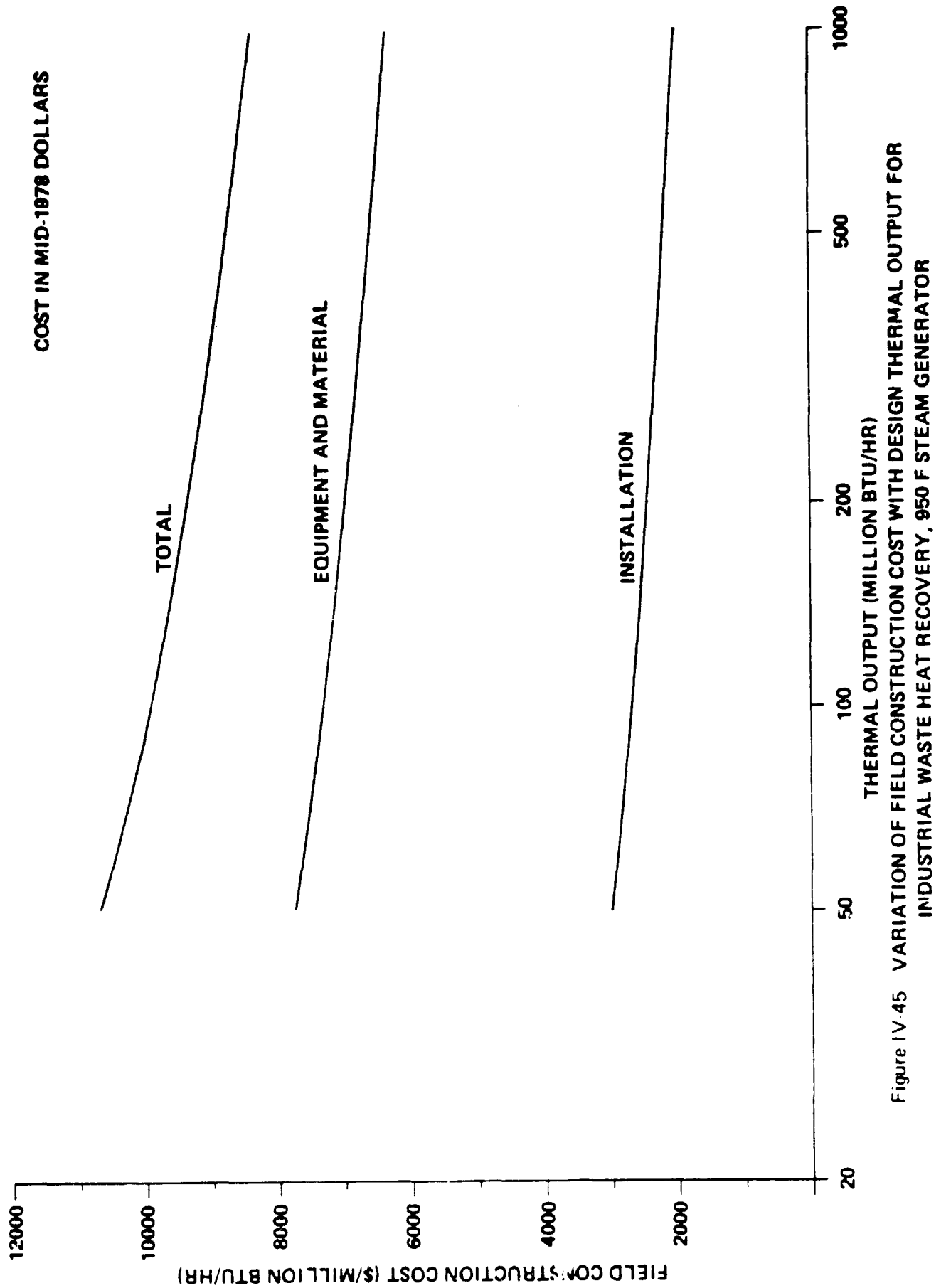


Figure IV-45 VARIATION OF FIELD CONSTRUCTION COST WITH DESIGN THERMAL OUTPUT FOR INDUSTRIAL WASTE HEAT RECOVERY, 950 F STEAM GENERATOR

TABLE IV-47
INDUSTRIAL WASTE HEAT, 950F STEAM GENERATOR
OPERATING PARAMETERS
(250 MILLION BTU/HR)

<u>Stream Number</u>	<u>Flowrate (lb/hr)</u>	<u>Temperature (F)</u>	<u>Pressure (psia)</u>
1	1,190,000	1000	14.7
2	1,190,000	300	14.5
3	211,000	240	25.0
4	164,000	240	1365.0
5	162,000	950	1215.0
6	47,500	240	85.0
7	47,000	304	69.0
8	47,000	300	65.0

TABLE IV-48

INDUSTRIAL WASTE HEAT RECOVERY, 950F STEAM GENERATOR

ENVIRONMENTAL INTRUSION

<u>Stack Gas Emissions</u>	<u>Predicted Rate (lb/million Btu)</u>
Sulfur Dioxide	*
Nitrogen Oxides	*
Hydrocarbons	*
Carbon Monoxide	*
Particulates	*
<u>Wastes Discharged</u>	
Water (Blowdown)	4.7
Dry Solids	0
Wet Solids	0
<u>Water Required</u>	
(Exclusive of Boiler Feed Water)	0
<u>Steam Required</u> (50 psig, 300F Condition)	
Fuel Atomizing	0

*Dependent on the process hot gas source.

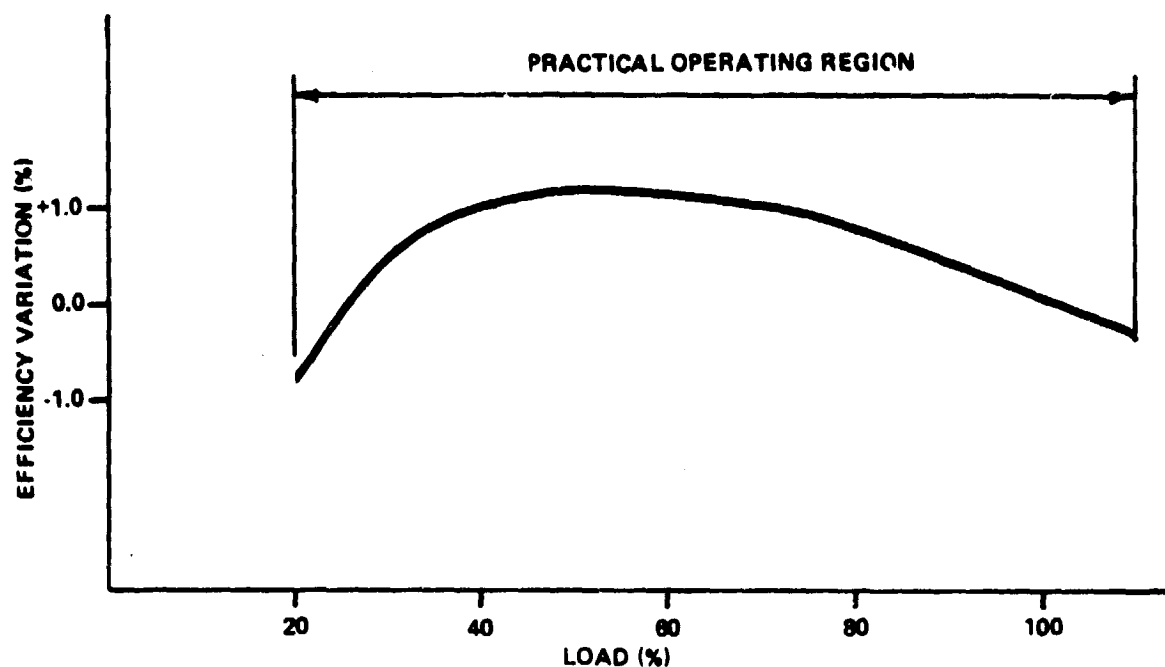


Figure IV-35 VARIATION OF THERMAL EFFICIENCY WITH PERCENT LOAD FOR THE ATMOSPHERIC FLUIDIZED BED, 1050 F STEAM GENERATOR

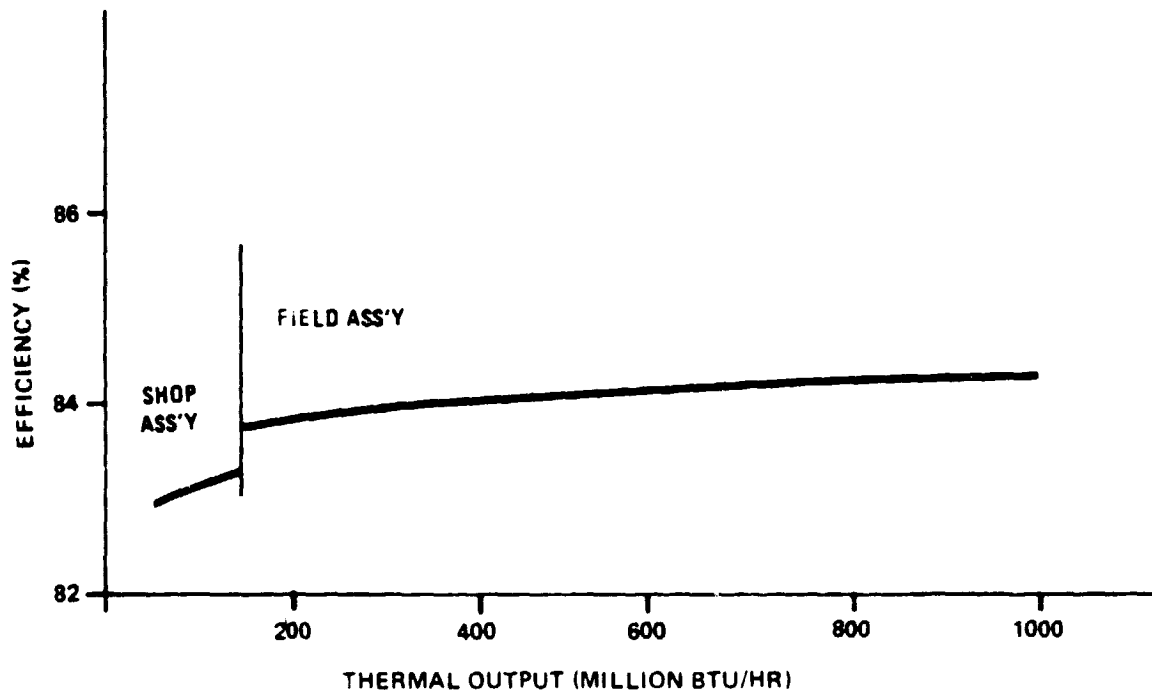


Figure IV-36 VARIATION OF DESIGN POINT EFFICIENCY WITH DESIGN POINT OUTPUT FOR THE ATMOSPHERIC FLUIDIZED BED, 1050 F STEAM GENERATOR

TABLE IV-49

INDUSTRIAL WASTE HEAT RECOVERY, 950F STEAM GENERATOR

FIELD CONSTRUCTION COST

(250 MILLION BTU/HR)

<u>ITEMS</u>	<u>DOLLARS</u>
Equipment	
Furnace (incl. boiler and economizer)	1,540,000
Other Equipment	45,000
Civil/Structural	17,000
Piping/Instrumentation	<u>105,000</u>
Total Equipment and Materials	1,707,000
Direct Installation Labor (@ \$14/MH)	340,000
Indirects (@ 75% of Direct Labor)	<u>255,000</u>
Total Field Construction Cost (Mid-1978 Dollars)	2,302,000 =====

C. THERMAL ENERGY STORAGE

1.0 INTRODUCTION

Simultaneous production of electrical and useful thermal energy (cogeneration) offers the possibility of vast savings in national energy consumption. It has been estimated that energy savings equivalent to 5.1 million barrels of oil per day are achievable through conversion of both the industrial sector and the municipal/private sectors to cogeneration (Reference 4). Inherent in this estimate is the assumption that energy can be stored when the demand for electric energy causes the production of more thermal energy than the need and retrieved from storage when the demand exceeds the production.

For a given industrial site, the ability to purchase electricity from the utility grid and sell back surplus production introduces a host of alternate strategies to be evaluated in the design of a cogeneration system. It is the purpose of the study reported herein to assemble sufficient data concerning the operation, efficiency, and cost of thermal energy storage systems so that their potential role in conjunction with cogeneration systems can be assessed. A wide variety of industrial systems is to be analyzed which precludes optimizing the thermal storage system for any particular case. Presented then is relatively generalized data which will not necessarily represent the best design for a given case but will, hopefully, not miss the mark by far for any case.

Two parameters upon which a given energy storage system design will most heavily depend are 1) the fluid by which the energy is transported and 2) the temperature at which the energy is available. It is assumed that the carrier fluid by which energy will be supplied to the process from storage is the same as that supplying energy to storage. A certain temperature difference between energy supplied to storage and energy withdrawn from storage must be allowable. In general, the storage density (Btu ft^{-3}) and the specific cost ($\$/\text{Btu stored}$) are strong functions of this allowable temperature difference, higher allowable temperature differences yielding high storage densities and lower specific costs. Much of the optimization process for a specific application involves the tradeoff between the undesirable loss of availability of the energy stored and the desirable higher storage density and decreased cost.

A temperature spectrum from 140 to 1,000°F is to be covered. To avoid overgeneralizing the storage system, this spectrum is divided into five categories termed "bins". Table IV-50 lists the temperature spans, the fluid carrier, the selected storage material and containment, and a range of supply-withdrawal temperature difference typical of current practice.

The various energy storage means have been selected for a relatively well developed technology status in most cases so that a high degree of confidence for applicability in the 1985 through 2000 time frame is assured.

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Table IV-50
SEGREGATION OF STORAGE SCHEMES BY TEMPERATURE RANGE ("BINS")

Bin No.	Supply Temp. Range	Fluid Carrier	Storage Medium	Containment	Input-Output Temperature Difference
1	140°F to 212°F	Water	Water	Insulated welded steel tank, large systems may justify aquifer storage.	~5°F
2	212°F to 300°F	Steam (Saturated)	Water (Saturated)	Insulated welded steel tank. Prestressed cast iron vessel at high temp. (hot tank, cold tendons)	30 - 60°F
3	300°F to 500°F	Steam (Saturated)	Water (Saturated)	Insulated prestressed cast iron vessel Hot tank, cold tendons	30 - 100°F
4	500°F to 700°F	Steam (Superheated)	Water (Saturated) plus solid-molten salt	Insulated prestressed cast iron vessel (hot tank, cold tendon) phase change salt encapsulated in suitable passive metal containers.	60 - 100°F
5	700°F to 1000°F	Gas (Nominally air)	Solid sensible Medium 1) High MgO brick 2) Taconite pellets 3) Native rock	Simple double wall brick enclosure	10 - 20°F

2.0 INFLUENTIAL PARAMETERS FOR STORAGE SYSTEM DESIGN

The most influential variables for storage system design may be listed as 1) supply temperature, 2) fluid carrier, and 3) input-output temperature difference. In addition, however, the overall system size, the value of energy saved, and the duration of the fill (charge) and drain (discharge) cycles may have a strong bearing upon the particular optimum storage system. In an attempt to avoid overgeneralization, the five "bin" matrix of systems was chosen and appropriate fluid carriers and input-output temperature differences selected consistent with current practice. This allows the nominal selection of an energy storage medium and containment method. These selections may not be appropriate for very large systems.

2.1 SYSTEM SIZE EFFECTS

Figure IV-46 presents the effect of storage container size upon the cost of various storage containers. The same data, replotted as specific cost (\$/cubic foot) is included in Figure IV-47. Data from several sources for several containment means are shown. A, B, and C are the storage system costs predicted in Reference 2 for prestressed cast iron vessels at 10 MPa (1,450 psia), 6 MPa (870 psia), and 1 MPa (145 psia) respectively. The discontinuity in the slope of these curves is a result of differing mechanisms for peak stress buildup. In larger vessels, the cylindrical wall thickness is controlled by the hoop stresses; while in smaller vessels, local stresses in the vicinity of the insulation pads predominate. (Insulating pads space the tension members, called "tendons", away from the hot vessel itself.) Note that only for very large systems in excess of 10^5 cubic feet does the specific cost (Figure IV-47) yield a constant value. The data for curve B are fit to within 1 percent by the following relationship:

$$SC = 33.8405 + 4.626 \times 10^{-5} V^{-1}$$

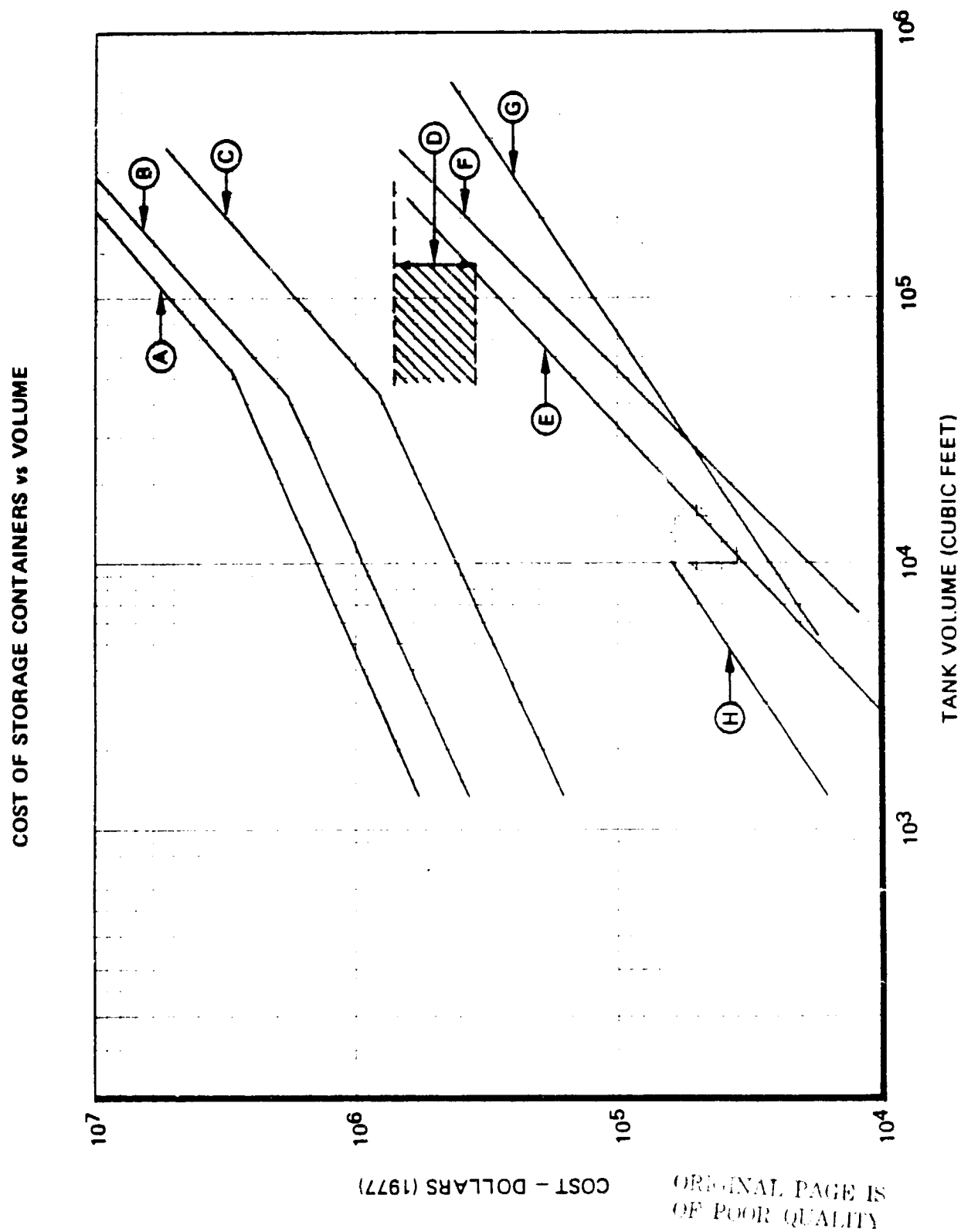
where:

SC = specific cost in 1974 \$/ft³

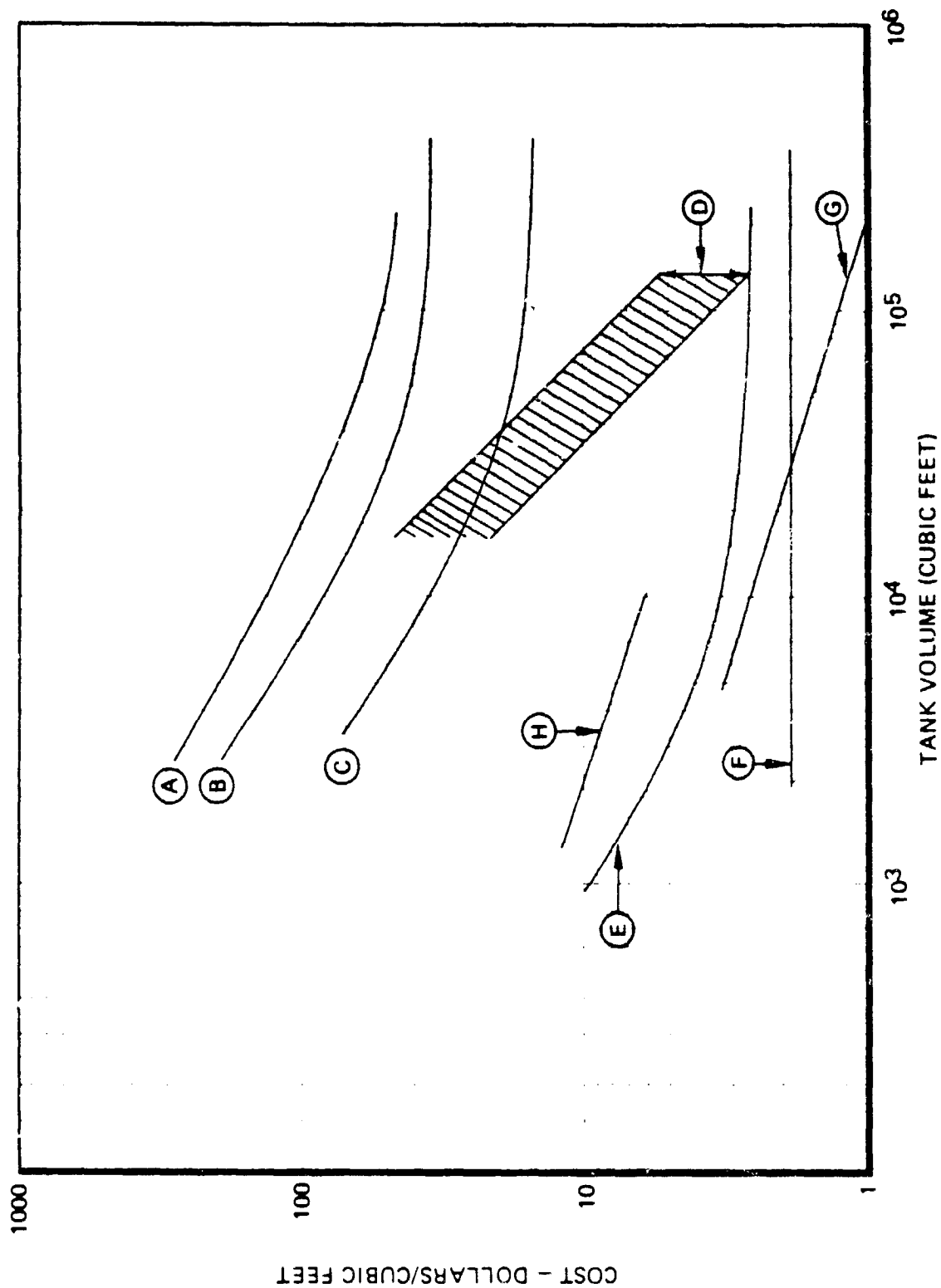
V = volume in ft³

Pressure effects are discussed in paragraph 2.2.

Item D in Figures IV-46 and IV-47 represents the span of cost estimates for a 10^6 gal/day heat storage well from Reference 4. The shaded area represents the same well used at less than full capacity. The cost estimate includes all required auxiliary systems including pumps, piping, and a heat exchanger to isolate the source water from the ground water thereby avoiding potential questions of contamination. The system is estimated to be applicable to temperatures as high as 400°F (pressure of 250 psia) through appropriately deep wells.



SPECIFIC COST OF STORAGE CONTAINERS vs VOLUME



Items E and F in Figures IV-46 and IV-47 represent recent supplier quotes obtained for Reference 5. Item E is for an insulated low pressure welded steel tank with acid resistant lining and item F is for the bare tank alone. If one follows the procedure recommended in Reference 3 for estimating system costs from component costs, the system costs will be roughly three times the major part cost. This will show a cost advantage for the aquifer system (D) for systems larger than the 1.3×10^5 ft³/day (10^6 gal) system.

Items G and H are the recommendations of Reference 3 for 15 and 150 psia welded steel tanks erected on-site. Actual data has been increased by 58 percent to account for inflation from the given 1970 data to the desired 1977 data. These are included due to Reference 3's position as a standard reference work in this field; items E and F probably represent more realistic bounds to current-day prices.

2.2 EFFECTS OF PRESSURE LEVEL ON SPECIFIC STORAGE COST

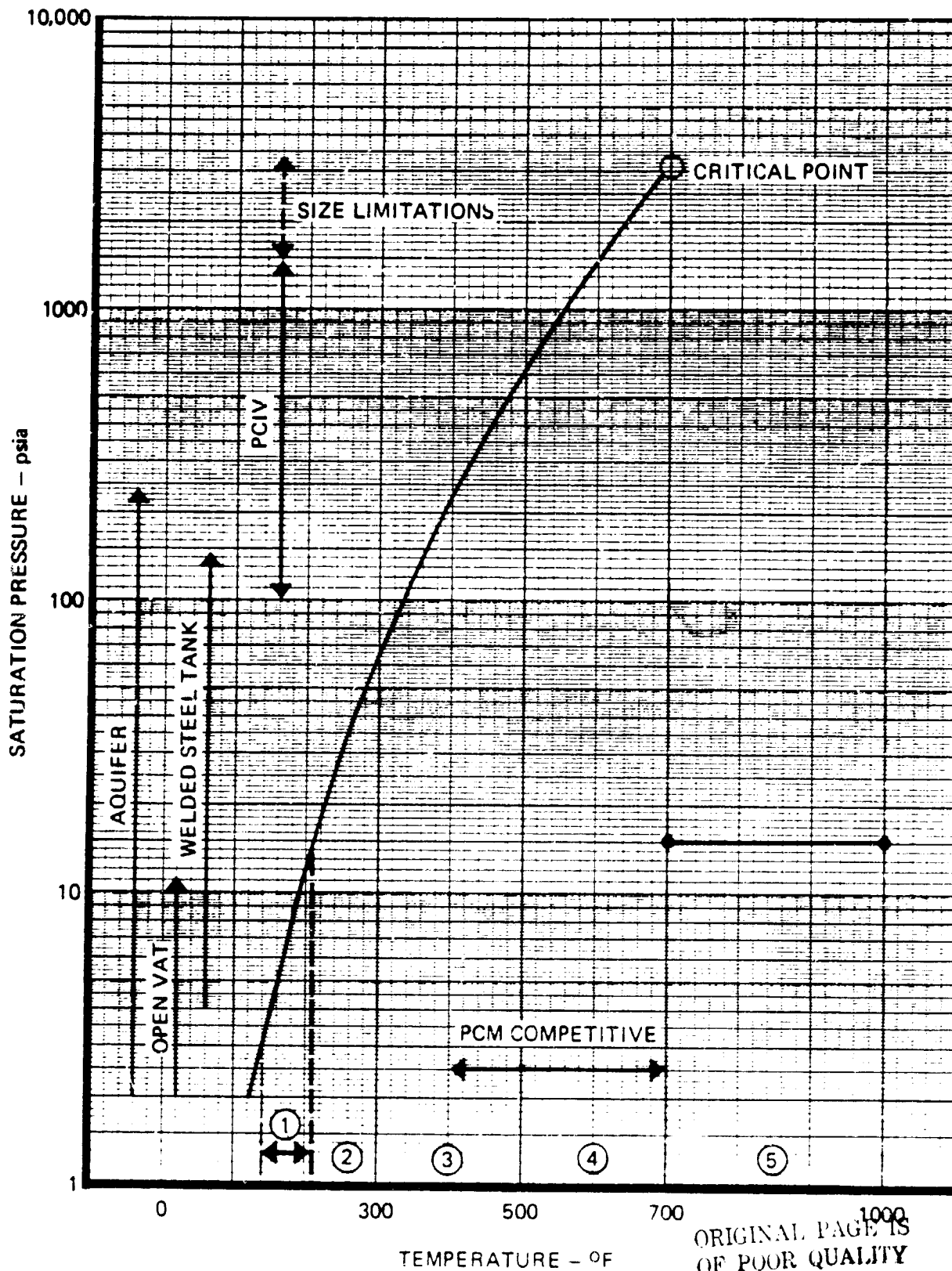
Selection of water as the carrying fluid links system supply temperature with system pressure through the saturation characteristic. In Figure IV-48, the saturation pressure of water is shown as a function of system temperature. The temperature ranges of the five "bins" are noted. Pressure ranges for various containment means are indicated along the ordinate. Figure IV-49 presents the specific cost (\$/Btu) of the major system hardware against system temperature. To convert these data to installed-operational system costs, a multiplier between 2.5 and 3.0 may be applied per Reference 3.

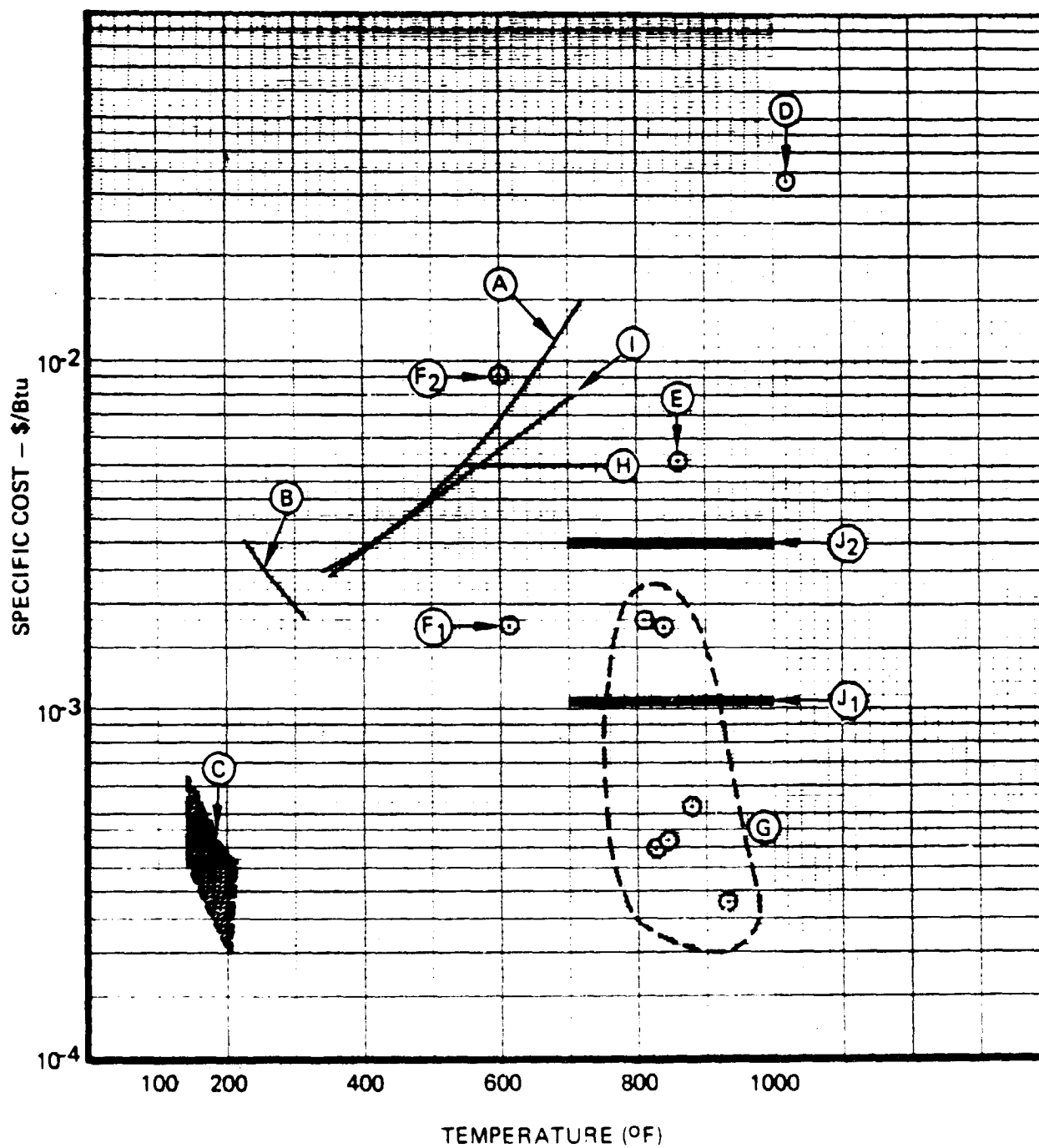
The effect of an increase in system design pressure, with all else unchanged, yields an increase in storage system wall thickness, hence an increase in the thermal storage effect of the vessel itself. The latter effect is significant, Reference 1 showing the increase to be as high as 45 percent at higher pressures. While mitigating the increased price of the storage system, the energy storage effect of the vessel does not completely compensate, hence the specific cost (\$ per Btu stored) increases with increasing pressure.

Open vats (free surface insulated by various floating means such as glass microspheres, styrofoam beads, etc.) are suitable storage means up to a partial pressure of roughly 12 psia ($\sim 200^\circ\text{F}$). Above this level, evaporation loss prevention becomes very significant. Welded steel tanks are cost competitive down to perhaps 5 or 6 psia partial pressure. The slight additional cost of a welded tank over a vat for the lower temperature regime of bin 1 will, in many cases (i.e., boiler feed water storage) be justified through the requirement to maintain the water in a deaerated condition. Welded steel tanks are therefore selected as the nominal containment means for bin 1, recognizing that somewhat less expensive means may be allowable in some specific cases. For very large systems, aquifer storage will show a cost edge for systems at pressures less than 250 psia (supply temperature less than 400°F) as mentioned in paragraph 2.1.

In Figure IV-49, the specific cost of water stored in pressurized steel tanks is shown as shaded area C. It is assumed for this calculation that the water would be seweraged if not stored, and that makeup water would be heated to the desired temperature from potable supply. The temperature of this

SATURATION PRESSURE OF WATER (AND CONTAINMENT REGIMES)
AS A FUNCTION OF TEMPERATURE



SPECIFIC COSTS OF HARDWARE COMPONENTS
AS A FUNCTION OF STORAGE TEMPERATURE

supply is taken as 52°F, representative of a reasonable national average, from Reference 7. The decrease of specific storage cost with storage temperature for this case represents the increase in energy which would have to be added to make up water to achieve the higher temperature. The decrease in density of the stored water with increasing storage temperature, while accounted for, is not a strong effect. The lower bound for the shaded area is for very large systems.

The temperature range of the second bin yields a pressure range from atmospheric through 67 psia. A welded steel tank is the most likely choice for containment in this regime. Again, aquifer storage may be indicated for very large systems. In Figure IV-49, the specific storage cost is shown as line B. A temperature difference between supply and demand of 60°F was used above 272°F. Below 272°F it is assumed that saturated steam at atmospheric pressure is the system output.

For bin number three, the regions of welded steel tanks and prestressed cast iron vessels (PCIV) overlap. A clear cost advantage for the former exists for the lower range; a clear cost advantage for the latter exists for the higher range. Further complication in the selection of an energy storage system arises for bin number 3 as phase change materials may show a cost advantage in the upper temperature portion of this bin in the time frame of interest. It is recommended that the analysis for bin 3 be based upon a PCIV steam accumulator operating in the varying pressure mode to avoid excessive computational complexity. In Figure IV-49 the appropriate line for the third bin is labeled A. This curve is based upon the data of Reference 2 and assumes a 100°F temperature difference from input to output. It should be noted that this is an upper limit for such a system, as either thermal stresses in the cast iron vessel or loss of tension in the tendons may result from rapid discharge through larger temperature changes.

The fourth bin covers situations where steam is available for storage at a temperature between 500 and 700°F. Saturation pressure at these temperatures varies from 680 to 3,100 psia. Varying-pressure, steam-accumulator technology has been selected as the nominal energy storage means for this bin. At these pressure levels, PCIV is likely to show a cost benefit over welded steel tanks. The specific cost of this item is shown on Figure IV-49, item A. The allowable temperature change is again taken at 100°F; with the effect of temperature being to the minus one power, i.e., halving the allowable temperature difference doubles the specific storage cost. It is very likely that some form of phase change material will be used to augment the steam/water storage at higher pressures. The higher storage density attainable with molten salt storage is already competitive with high pressure steam storage as shown by items F₁ and F₂. These are the cost of the salt itself in the Comstock and Wescott NaOH storage system (Reference 6) and the overall system cost for that system (Reference 10). Many eutectics are known with fusion temperatures in this region (Reference 9 lists 724), although most of the development work is being done with somewhat higher temperature materials as shown in the group labeled G -- a number of (nonlithium) alkali metal chlorides (Reference 6). Generally, a eutectic with an appropriate fusion temperature may contain a large fraction of one of the salts shown in G plus an appropriate amount of lithium salt. Lithium salts are generally more expensive than other alkali metal salts as shown by item D (lithium bromide) and item E (lithium hydroxide). Hence, the overall storage material cost for PCM augmented systems in the desired temperature range will likely fall somewhat above the G region. The selection of a salt

for any specific design must trade off cost against storage density, corrosiveness, safety in handling (small amounts of nitrate salts may be tolerable), etc. In an attempt to preguess the result of these trade-offs over the entire region, a system cost midway between F₁ and F₂ would appear achievable in very large quantities by the 1985 to 2000 time period.

This broad brush approach, yielding 5×10^{-3} \$/Btu stored in molten salt (item H, Figure IV-49), is as representative an estimate as is feasible using currently available information. An accuracy of +100%/-50% for this figure could be applied to yield high confidence levels. Line I on Figure IV-49 represents an estimate of the combined system cost of PCIV steam storage incorporating submerged encapsulated PCM storage in the higher pressure regime. The line is fit by the relationship:

$$\text{Specific cost} \left(\frac{\$}{\text{Btu}} \right) = 7.5 \times 10^{-4} e^{3.337 \times 10^{-3} T}$$

where T is degrees F.

The fifth bin is characterized by an energy supplied in gas at a temperature between 700 and 1,000°F. It is assumed that the gas properties are similar to air. The pressure level is not specified; however, it is assumed that near ambient pressures will prevail. Item J shows the predicted specific cost of energy stored as sensible energy in a solid medium, nominally high MgO brick, for the medium alone (comparable to items D, E, F, and G). Item J₂ shows the predicted overall system cost (comparable to items A, B, C, F₂, and H). Alternate solid materials which may show an advantage over this system for specific sites are 1) taconite (iron ore) pellets and 2) native rock.

Unknown site specific parameters which could effect the overall system design significantly include supply gas stream cleanliness and the rate at which the system is to be charged and discharged. The latter effect is particularly important for this type energy storage due to the inherent temperature differences required within the solid shapes (bricks, pellets, irregular masses) to effect heat transfer from and to the surface.

In summary, the recommended factors by which to assess the cost of storage within the bins are accumulated in Table IV-51 along with several important properties and parameters which lead to its calculated value.

2.3 SYSTEM FOOTPRINT

The floor space required for an energy storage system is a cost item in that its utility is lost for other (profit making) ventures. The effect is not included in the specific cost data furnished in paragraph 2.2 and will be covered under parallel investigation to that herein reported.

System footprints are a direct function of system size (aquifer storage excepted). All systems recommended for the baseline investigation are vertical axis cylinders. Through a knowledge of the length to diameter ratio (L/D) and the total energy to be stored, the required area (A) may be found.

Table IV-51
SPECIFIC COST DATA VERSUS TEMPERATURE RANGE

Bin No.	Temp. °F	P _{sat} psig	ρ _c #/ft ³	A _s Stored h _L	Discharged h _e	Δh Btu/lb	Iron Effect	Storage Density Btu/ft ³	Sp. Cost \$/ft ³	Specific Cost \$/Btu	Average Storage Density Btu/ft ³	Average Specific Cost \$/Btu
1	140	2.9	61.4	107.9	107.9	87.9	1.00	5,397	2.5	6.5×10^{-4}	7,526	4.5×10^{-4}
	170	6.0	60.8	137.9	137.9	117.9	1.00	7,168	3.5	4.9×10^{-4}		
	200	11.5	60.1	168.0	168.0	148.0	1.00	8,895	3.5	3.9×10^{-4}		
	212	14.7	59.8	180.0	180.0	160.0	1.00	9,568	(3.5)	3.65×10^{-4}		
2	250	29.8	58.8	218.48	180.0	38.48	1.00	2,262	6*	2.6×10^{-3}	1,750	2.6×10^{-3}
3	300	67.0	57.3	269.59	208.3	61.35	1.00	3,515	10*	2.8×10^{-3}	5,130	7.5×10^{-4} e0.003337 T
	350	137.6	55.6	321.63	218.48	103.15	1.00	5,735	14.2	2.47×10^{-3}		
	400	247.3	53.6	374.97	269.59	105.38	1.08	6,100	17.36	2.84×10^{-3}		
	450	422.6	51.5	430.1	321.63	108.47	1.17	6,535	22.4	3.42×10^{-3}		
4	500	680.8	49.0	487.8	374.97	112.83	1.22	6,744	29.9	4.43×10^{-3}	7,341	7.5×10^{-4} e0.003337 T
	550	1,045.2	45.9	549.3	430.1	119.2	1.28	7,003	40.40	5.77×10^{-3}		
	600	1,542.9	42.4	617.0	487.8	129.2	1.36	7,450	54.8	7.35×10^{-3}		
	650	2,208.2	37.3	695.7	549.3	146.4	1.44	7,863	74.0	9.41×10^{-3}		
700	3,093.7	27.1	823.3	617.0	617.0	206.3	1.42	7,938	99.5	12.5×10^{-3}	11,475	3×10^{-3}
5	700 to 1000	Na	88.5	Na	Na	135.0	Neg- ligible	11,950	36.0	3.0×10^{-3}		

*Void fraction of 0.50 assumed.

$$A = 0.9226 \left(\frac{V}{L/D} \right)^{2/3}$$

The required volume is the quotient, total energy to be stored divided by the storage density from Table IV-51.

The length to diameter ratio for a vertical axis cylindrical storage vessel tends to be limited at the high end by the bearing properties of the earth below the site. The desire to minimize surface area to reduce heat losses (and/or insulation costs) tends to yield aspect ratios of the order of unity when footprint costs are low. For higher pressure vessels, hoop stress considerations urge the design towards very high aspect ratios. For a given design, data will exist by which these competing effects can be arbitrated. Table IV-52 shows the L/D ratios assumed.

Table IV-52
ASSUMED STORAGE VESSEL
LENGTH/DIAMETER RATIOS

<u>Bin No.</u>	<u>L/D</u>
1	4.0
2	5.75
3	5.75
4	5.75
5	1.0 to 1.25

L/D's for bins 2, 3, and 4 are the data of Reference 2. A somewhat lower figure is suggested for Bin 1 to limit the hydrostatic head to values consistent with "unpressurized" welded steel tanks. The brick enclosure recommended for Bin 5 is recommended at a relatively low L/D of less than 2 for two reasons. The first of these is earthquake resistance. The second is that for longer system, parasitic power will rise unless the fraction of void space is increased. Increasing the void fraction (50 percent assumed) requires progressively larger systems defeating the purpose of a greater L/D.

3.0 SYSTEM DESCRIPTION

The following paragraphs describe the 5 energy storage systems appropriate for the five temperature bands. In all cases, the system round trip efficiency is limited not by engineering principles but rather by economic inputs. Hence, thermal losses from the storage container and its associated piping or ductwork can be decreased with the application of additional insulation. Depending upon the volume of energy at the time of actual construction, the most cost-effective investment in insulation can be defined. A similar situation exists in the tradeoff between pipe (duct) size and parasitic power requirements. In a general survey such as the one herein reported, recourse is had to generalized current practice.

3.1 HOT WATER STORAGE

A schematic hot water storage system is presented in Figure IV-50. Retrofit considerations are simplified through a system design incorporating a single break/tie-in to existing supply lines.

3.1.1 Instrumentation and Control Systems

As hot water demand decreases, the supply line pressure will increase. Sensing the increased pressure opens the storage system fill valve. Increasing demand will decrease the supply line pressure activating the tank discharge valve and pump. Liquid level sensors guard against overfilling and against reducing the liquid level to the point where gas is introduced into the supply line. A simple burst diaphragm guards the tank against overpressure from unforeseen system malfunctions.

3.1.2 Development Status

Systems of this type have been used industrially for many years. A common application allows increased peak boiler steam output through the storage of preheated feedwater heated during low demand periods.

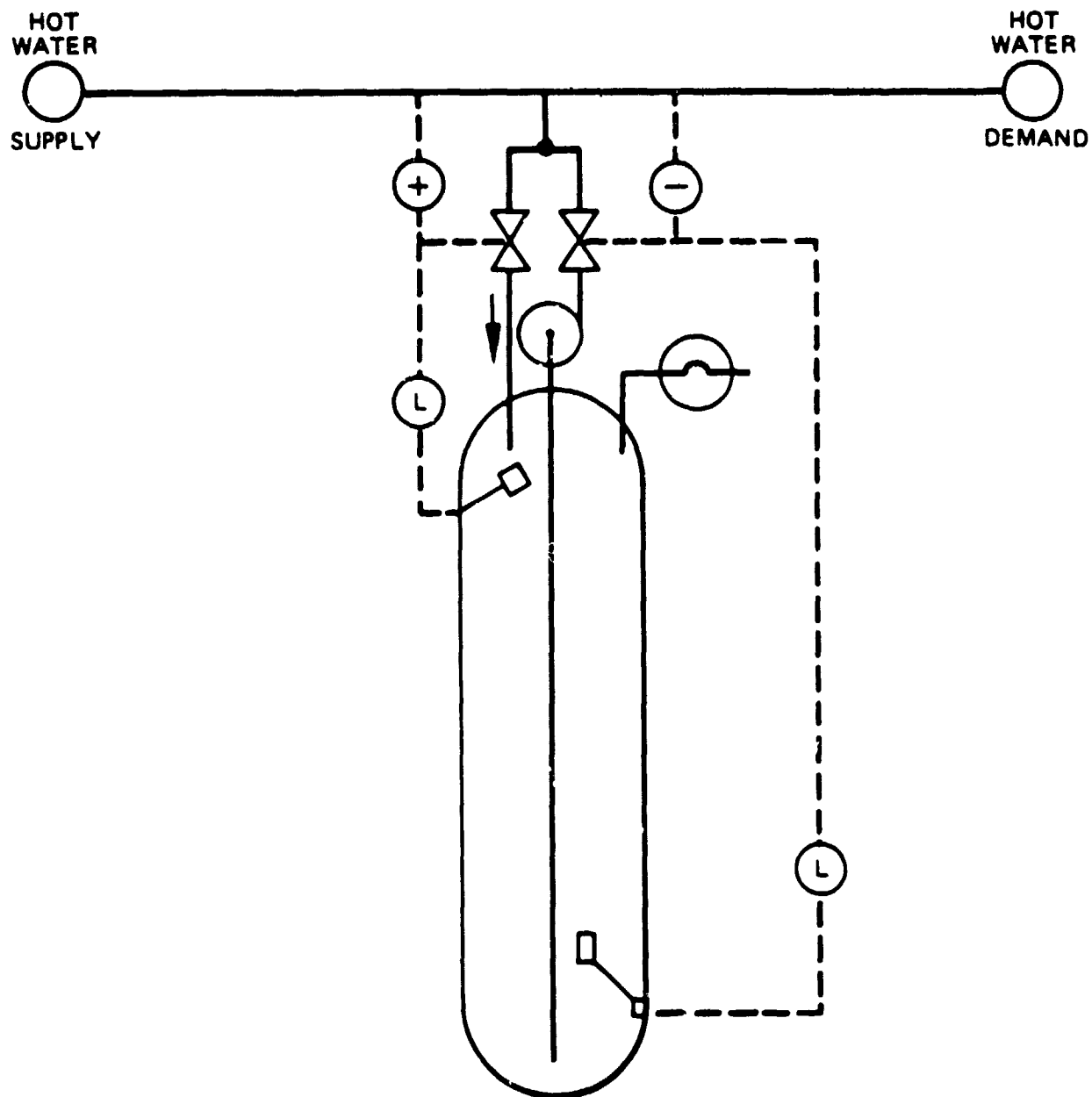
3.1.3 Parasitic Power

Neglecting the very slight electrical requirements of the pressure sensing valves, the only power required by the system is that to drive the pump. This occurs only during discharge portion of the cycle. Assuming that the system can be close coupled to existing piping, large pipes can be selected at a minimum cost penalty resulting in minimal parasitic power requirements.

For example, a system delivering water at 176°F (the mid temperature of Bin 1) at 1.15×10^5 lbs/hr saves 123.9 Btu/lb, hence delivering 1.42×10^7 Btu/hr. With a piping system effectively 100 feet long and 3 inches in diameter, a pump power of 1-1.2 horsepower is required. The ratio of parasitic power to energy delivered is 0.00027. Increasing the pipe diameter to 4 inches decreases the required power by a factor of five. It is recommended that parasitic power requirements of this system be neglected.

BIN NO. 1 - HOT WATER STORAGE
ENERGY STORAGE SUBSYSTEM SCHEMATIC

- | | |
|------------------------|--------------|
| • SUPPLY/DEMAND MEDIUM | WATER |
| • STORAGE MEDIUM | WATER |
| • TEMPERATURE RANGE | 140 to 212°F |
| • DEVELOPMENT STATUS | IN USE |



3.1.4 Thermal Losses and Round Trip Efficiency

Irrespective of the fill-drain cycle, the storage system will maintain a high temperature inner wall 24 hours per day. Losses then on a 24-hour time frame must eventually be withdrawn from the stored liquid. For a cylindrical tank with a length (L) to diameter (D) ratio of 4, the surface area to volume ratio is $4.50 D^{-1}$. Taking a nominal storage temperature of 176°F, an ambient of 70°F, and an insulation conductivity typical of inexpensive, available materials at 0.023 Btu/ft-°F-hr (glass wool), the energy lost as a fraction of the energy capacity may be found as a function of the product of insulation thickness (b) and tank diameter (D).

$$\frac{\text{Energy lost}}{\text{Energy capacity}} = \frac{0.0353}{Db}$$

where:

- D = tank diameter in feet
- b = insulation thickness in feet

This calculation ignores the resistance to heat transfer of the inner tank-fluid interface, the tank wall itself, and the outer insulation-air interface and is thus conservative.

A 10-foot diameter tank with a 1/2 foot insulation blanket yields a predicted tank thermal loss less than 1 percent.

Close coupled piping systems yield additional benefits in reduced thermal losses as well as minimal parasitic power. Paying close attention to insulation at bends and elbows, coupled with present piping insulation practice, can limit losses to less than 1 percent of the energy carried; thus an overall thermal loss less than 2 percent and a round trip efficiency of 98 percent are achievable parameters for this type of system.

3.2 LOW PRESSURE STEAM STORAGE

A schematic of a low to medium pressure steam storage system is presented in Figure IV-51. Steam is shown supplied from a pressure tap in a turbine; however, any steam source of somewhat higher temperature and pressure than the low pressure steam demand will suffice.

Steam is fed into the submerged distribution device where it condenses, transferring its energy to water. Water temperature is raised to the saturation temperature characteristic of the storage system pressure. Hence the major amount of stored energy is in the enthalpy of the saturated water. Upon demand, a decrease in the storage pressure results in a large mass of superheated water, a fraction of which will flash to steam very rapidly, the latent heat of vaporization being drawn from the remaining liquid until saturation condition at the new pressure is reached.

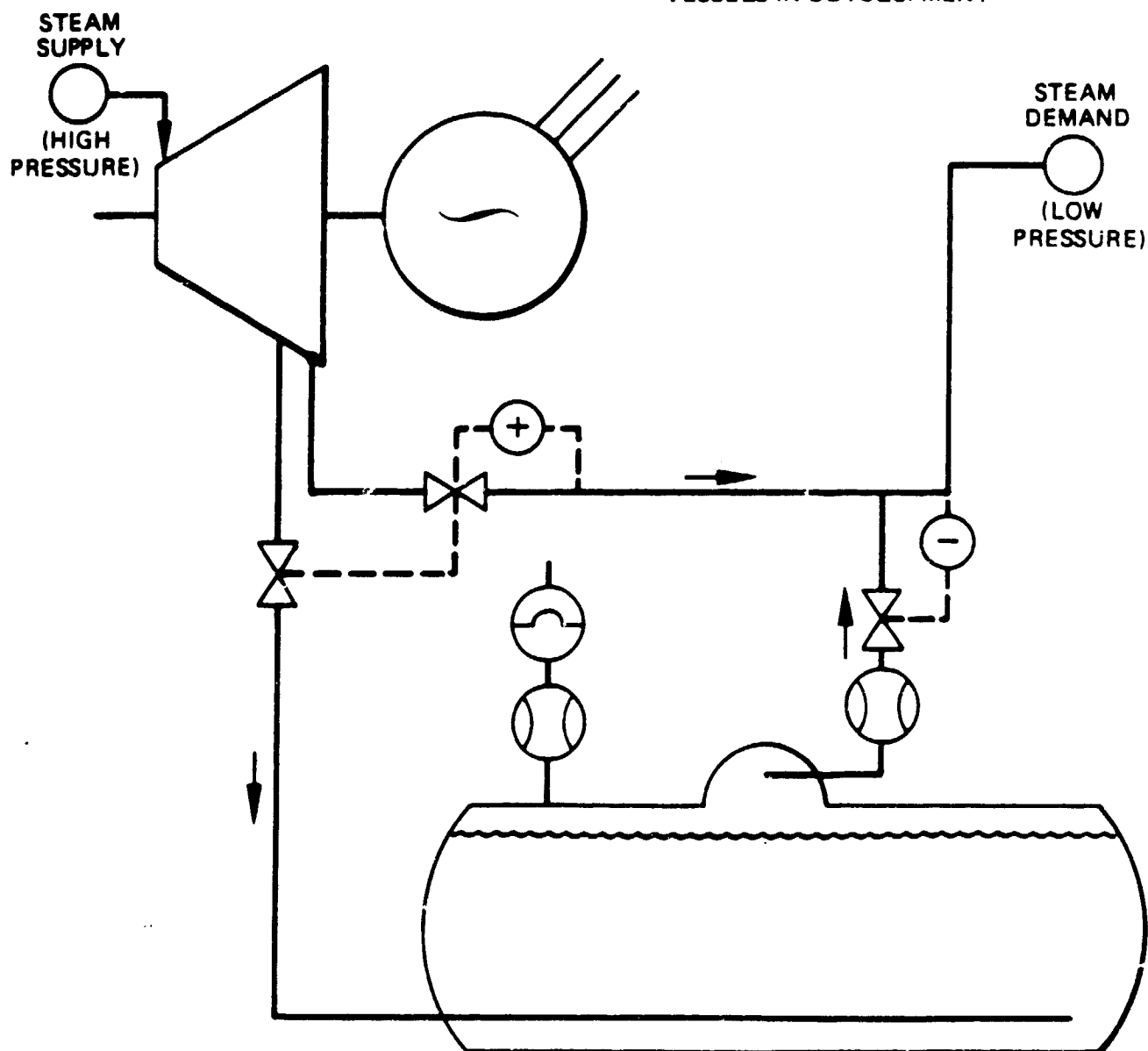
3.2.1 Instrumentation and Control Systems

Decreasing demand for low-pressure steam is sensed by the increasing line pressure. This signal is used to open the steam top line from the turbine and may also partially close the main steam

**BIN NOS. 2 & 3 – LOW TO MEDIUM PRESSURE STEAM STORAGE SYSTEM
ENERGY STORAGE SUBSYSTEM SCHEMATIC**

- SUPPLY/DEMAND MEDIUM
- STORAGE MEDIUM
- TEMPERATURE RANGE
- DEVELOPMENT STATUS

STEAM
WATER
212 to 300°F
& 300 to 500°F
IMPROVED PRESSURE
VESSELS IN DEVELOPMENT



demand line. Increased demand for steam is sensed by a low steam line pressure and opens the line from the storage system. Venturi flow limiters are arranged both in the accumulator discharge line and in the burst diaphragm device. These devices limit the steam flow to tolerable levels in the case of line rupture, as the inherent response of these devices to lowered pressure is extremely rapid.

3.2.2 Development Status

The technology of low and medium pressure steam accumulators was developed in the 1910 to 1920 time frame. A steam storage installation of a quarter of a million gallons was developed in 1921. The technology is thus well developed.

3.2.3 Parasitic Power

Other than the slight electrical needs of the valves and instrumentation, there is no parasitic power required by these systems.

3.2.4 Thermal Losses

Thermal losses from this type of system are manifested by a reduced system pressure. Frequently a slight steam bleed is arranged to make up the thermal loss. If the charge-discharge cycle is of 24-hour duration, then losses occurring over the entire cycle must be charged against the storage capacity. Analysis similar to that of paragraph 2.1.4 yields a surface area to volume ratio of $4.348/D-1$ for a cylinder with a length to diameter ratio of 5.75. At the mid bin temperature of 256°F, a discharge demand temperature of 212°F, and an ambient temperature of 70°F, the relationship between energy loss (as a fraction of energy stored), tank diameter, and insulation thickness is found as:

$$\frac{\text{Heat lost}}{\text{Heat stored}} = \frac{0.173}{Db}$$

where:

D = diameter in feet

b = insulation thickness in feet

A 10-foot diameter tank with a 1.2 foot insulation blanket would be limited to 3-1.2 percent loss per day. Losses from lines and fittings may amount to 1-1.2 percent yielding an estimated loss of 5 percent per daily cycle or a round trip efficiency of 95 percent.

3.3 MEDIUM PRESSURE STEAM STORAGE

Schematically, the medium pressure steam storage system is identical to the low-pressure system shown in Figure IV-51. Pressure levels for this system may range from 67 psia to 680 psia. Whereas a welded steel vessel might be chosen for a design in the low temperature portion of this "bin", a prestressed cast iron vessel will likely show a cost advantage over most of the range and is thus chosen as the nominal approach.

3.3.1 Instrumentation and Control Systems

Instrumentation and control systems differ from those described in paragraph 3.2.1 only in pressure level.

3.3.2 Development Status

Technology for medium pressure steam storage is well developed. The prestressed cast iron vessel is a relatively recent development, an outgrowth of research towards containment for high temperature nuclear reactors. Original designs for this application used concrete rather than cast iron for the vessel wall. The advantages of this system over welded steel vessels were (Reference 2) relative freedom from crack propagation, ease of erection on site, and the ability to contain higher pressures through the use of high tensile materials for the tendons. The latter advantage is enhanced through the ability to keep these members in a relatively low temperature environment. Disadvantages of the prestressed concrete vessel arise from the relatively low strength of concrete, shrinkage and creep effects in concrete, the possibility of pressurized cracks (in the event of a leak in the liner, the effective radius of the pressure vessel increases, increasing the stress level), and finally, the necessity to maintain the concrete at relatively low temperatures.

Substitution of cast iron for concrete in the vessel design is reported to alleviate all of these disadvantages. A test vessel has been built in Germany and is under evaluation. No fundamental reason which could prevent this technology from being available in the 1985 to 2000 time period was located.

3.3.3 Parasitic Power

Other than the slight power requirements for instrumentation and valving, no electrical power is required by the system.

3.3.4

The prediction of the relationship between insulation thickness and vessel diameter is identical to that for low pressure steam presented in paragraph 3.2.4 except in temperature level. Thus, the surface to volume ratio is $4.348 D^{-1}$. At the mid range temperature of 400°F, a discharge demand temperature of 300°F (maximum allowable) and an ambient temperature of 70°F the relationship between energy lost, tank diameter, and insulation thickness is found as:

$$\frac{\text{Energy lost}}{\text{Energy stored}} = \frac{0.1299}{bD}$$

where:

b = insulation thickness (ft)

D = vessel diameter (ft)

Thermal losses through the major portion of the cylindrical vessel can be limited to 2-1.2 percent by a 1.2 foot insulation thickness (10-foot diameter vessel). Heat losses through the pressurized

insulation pads which support the tension members away from the vessel wall will represent the major system loss. Reference 2 suggests overall storage efficiencies of 0.7 to 0.85. As the nominal pressure range for those studies was somewhat above the maximum considered in this "bin", the higher end of the range at 0.85 is suggested as a design figure.

3.4 HIGH PRESSURE STEAM STORAGE

Steam at 500 to 700° is the energy source for this system. If saturated, this steam would be at a pressure ranging from 680 to 3,200 psia. Steam systems pressurized to levels above 1,500 psi (600°F saturation) are uncommon, thus it is likely that the energy supplier in the upper temperature half of this bin would be superheated steam. Prestressed cast iron vessels should show a very significant cost advantage over other containment means for these pressure levels by the 1985 to 2000 time period.

Superheated steam storage, per se, is not known. Either a very considerable loss in availability is incurred in cooling and condensing at the available pressure or a very great expenditure in pumping power is required to pressurize to the saturation pressure. A certain amount of superheating of steam from an accumulator is possible by incorporating heat exchangers within the steam storage system; however, the net energy output is the same as for a saturated steam delivery system, hence the mass of steam delivered per unit volume of storage decreases.

The nominal system chosen to cover this band is applicable to systems where saturated steam is available as it is very unlikely that a system designed to store the energy from superheated steam would be cost effective. This system is presented schematically in Figure IV-52. It is very similar to that for low and medium pressure steam storage except that incorporation of one of the many known molten salt eutectic storage systems is projected. Essentially, the higher energy storage density of these materials will allow a required amount of energy to be stored in a smaller pressure vessel. Conceptually, the phase change material may be encapsulated in suitably inert containers and submerged in the pressure vessel. By choosing suitably small diameter containers, the desired system response may be achieved. Problems with phase separation and the progression of the liquid-solid interface which currently plague large-scale molten salt systems can thereby be circumvented.

Choice of the particular salt or salt eutectic will be specific to each installation. The family of alkali metal halides may provide a suitable eutectic choice for many systems with inclusion of alkali-hydroxides and smaller amounts of alkali metal carbonates or nitrates required in some cases.

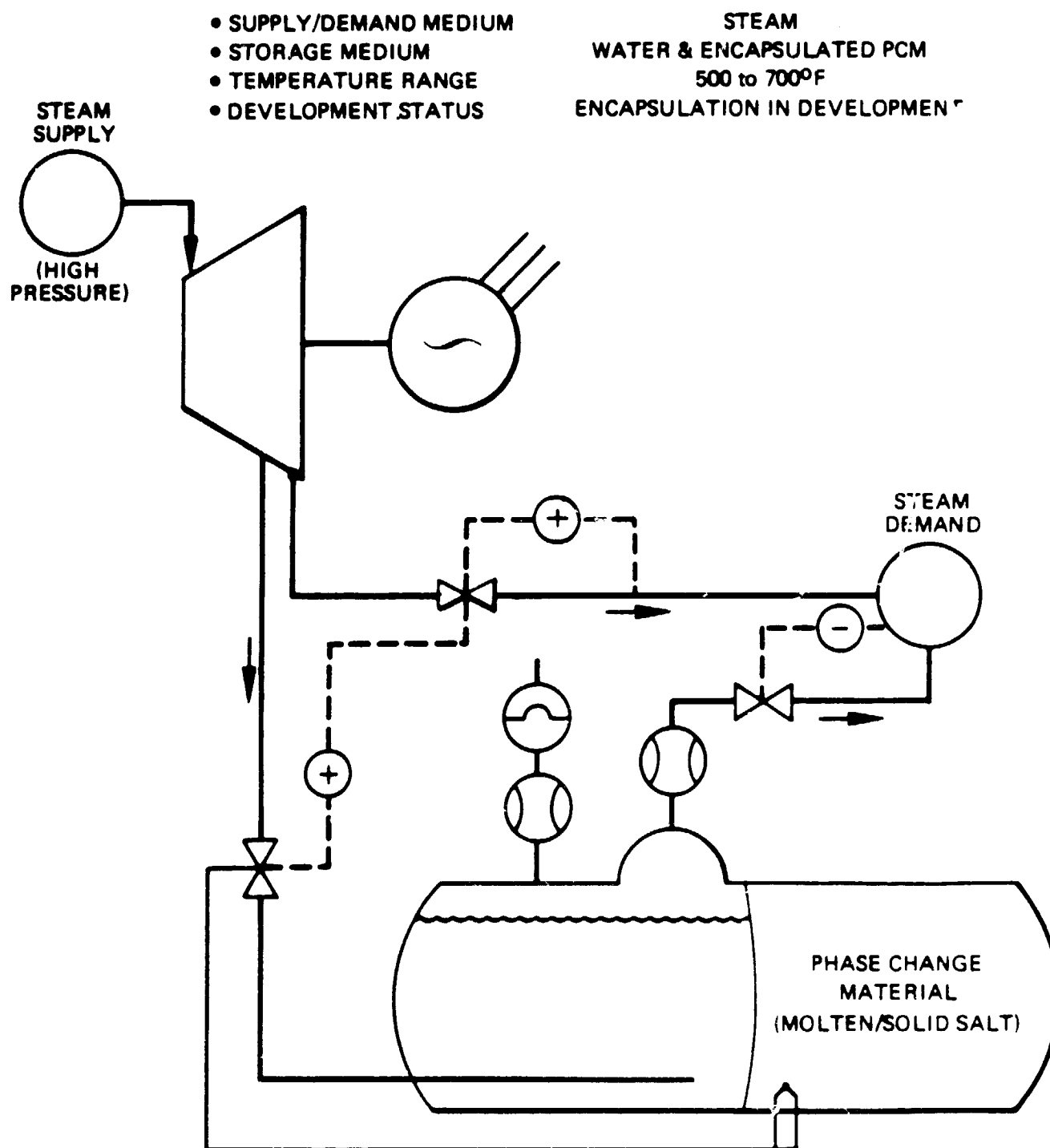
3.4.1 Instrumentation and Control Systems

The control system for the high pressure steam storage system is similar to that for low and medium pressure systems except that a temperature sensor indicating the status of the phase change material may be required to determine when the system is fully charged.

3.4.2 Development Status

The overall technology for high pressure steam storage was developed in the late 1930's. A 16,500 gallon (63 M³) system operating at 1,700 psi (120 kg/cm²) was constructed at that time as a source

**BIN NO. 4 – HIGH PRESSURE STEAM STORAGE SYSTEM
ENERGY STORAGE SUBSYSTEM SCHEMATIC**



for steam storage locomotion (Reference 1). The maturation of cost-effective prestressed cast iron vessel technology coupled with the rising value of energy should result in a resurgent interest in high pressure steam storage. Comments regarding the development status of PCIV's under paragraph 3.3.2 are equally pertinent here and need not be represented.

The status of molten salt energy storage techniques deserves some comment. The handling of many types of these materials is well known through their use in metal pressurization and heat treating applications. Extension of this technology to the storage of thermal energy is receiving considerable attention at the current time. No reason is foreseen why this technology should not be available in the time of interest.

3.4.3 Parasitic Power Requirements

The slight electric power requirements for instrumentation may be neglected for high pressure steam storage as well as medium and low pressure applications.

3.4.4

Major thermal losses from this system will arise through the insulating pads, similar to the case described under paragraph 3.3.4. For high pressure applications, the lower of the round trip efficiency calculations of Reference 2 at 70 percent should be used.

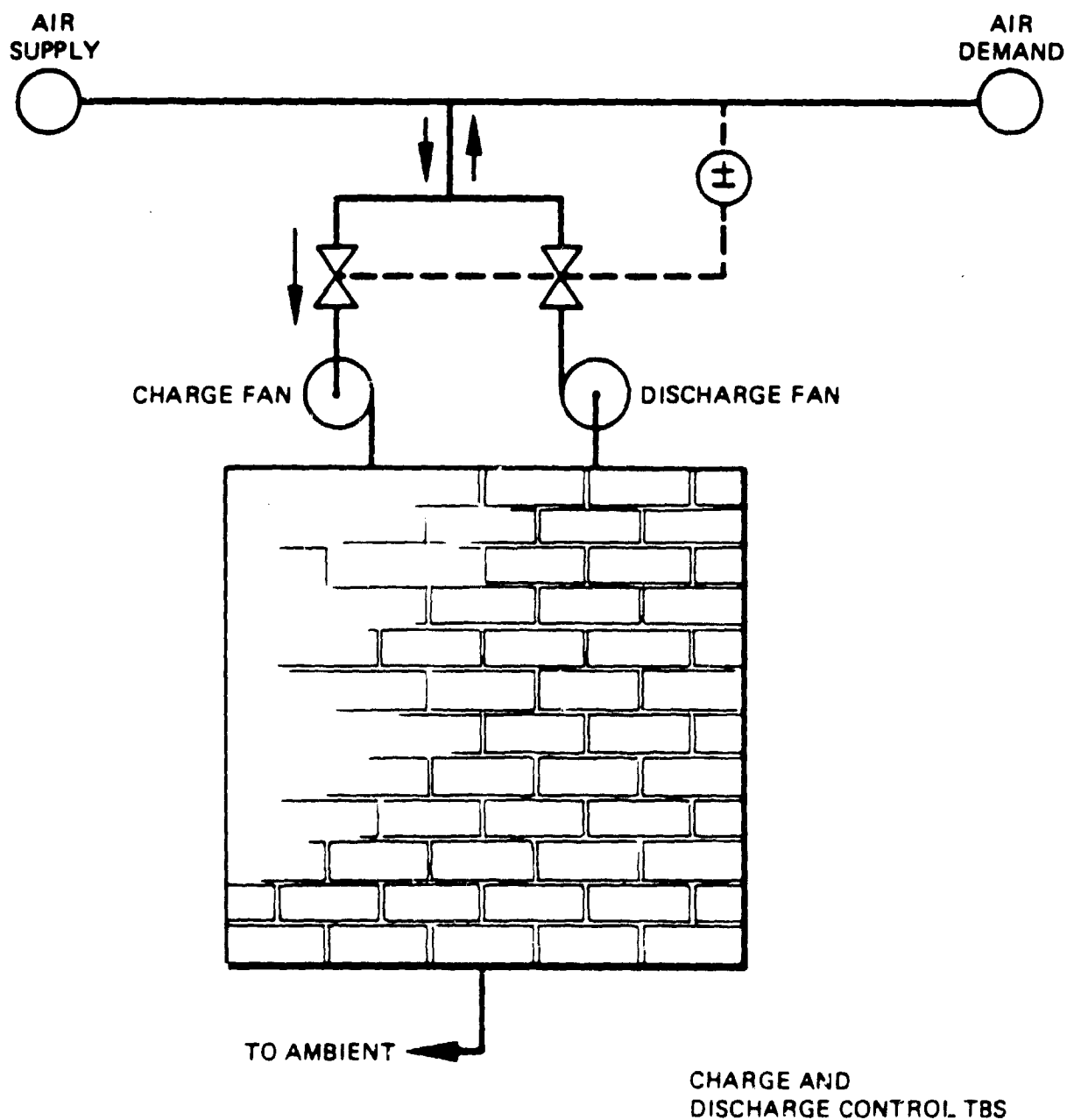
3.5 ENERGY STORAGE SYSTEM FOR 700 TO 1,000°F GAS (AIR)

Whereas many systems are known whereby energy from this source can be stored and retrieved, the most cost competitive system is likely to be a packed bed of solid material. Reference 11 presents an analysis comparing several energy storage means sized for a large concentrating solar collector-helium turbine system. A solid sensible storage bed was chosen on the basis of cost in that study. The study herein reported differs largely in pressure level (very significantly lower). The effect of this difference upon the cost calculations will be to decrease the storage system cost through the lack of requirement for pressurized containment and to increase the competitive cost edge for packed bed thermal storage techniques.

A schematic of the system is presented in Figure IV-53. A single entry into the supply duct serves both as a charge and discharge line simplifying the retrofit logistics. Blowers are arranged to force excess hot air through the storage bed or draw ambient air back through the system. The reversing of outflow direction in charge and discharge modes allows the system to behave somewhat like a countercurrent heat exchanger, thereby minimizing the difference between the temperature of gas available for charging the bed and that supplied to the demand by discharging the bed. Essentially a thermal front passes down the bed towards the exit during charging and back up the bed during discharging. Ideal analysis of these devices neglects thermal conduction in the axial bed direction, temperature differences within the storage material masses, heat losses in the radial direction, the resistance to heat transfer at the gas-storage mass interface and turbulence effects within the bed. This analysis yields a plane wave of thermal discontinuity (i.e., a step function) passing up and down the bed during charge and discharge like a piston.

**BIN NO. 5 – HIGH TEMPERATURE GAS STORAGE SYSTEM
ENERGY STORAGE SUBSYSTEM SCHEMATIC**

- SUPPLY/DEMAND MEDIUM AIR
- STORAGE MEDIUM MAGNESIA BRICK
- TEMPERATURE RANGE 700 to 1000°F
- DEVELOPMENT STATUS IN USE



Real bed effects modify the shape of this wave. The effect of radial conduction is to decrease the temperature of the bed at the system perimeter and yielding a domed piston shape for the thermal wave. The other effects smooth out the discontinuity yielding a situation most easily visualized as a series of isothermal planes of domed shape spaced one from another as a function of the degree of resistance to heat transfer at the surface, the amount of axial conduction, the amount of turbulence in the bed, and the temperature difference required to drive energy from the surface of each mass to its center.

3.5.1 Instrumentation and Control System

A pressure difference in the ductwork will exist as a function of the supply and demand for the energetic fluid. This may be considerably smaller for this system than for the steam system but should serve as a suitable indicator for a generalized description. Sensing this pressure difference (or other indications) serves to control power to both fans and valves. The valves are required to avoid "short circuit" flow loops.

3.5.2 Development Status

Systems similar to this are currently in use in many industrial situations, notably the checkerwork regenerators of the steel industry.

3.5.3 Parasitic Power Requirements and Thermal Efficiency

In any given design, system parasitic power trades off against system thermal efficiency. With the reversing flow charge-discharge mode, the major thermal loss occurs not from the radial conduction losses, but when the temperature of the gas exhausted to ambient exceeds ambient temperature. This will occur towards the end of the charging cycle as the first of the envisioned isotherms passes the end of the storage bed. By making the bed long enough, this effect need never happen. The penalty, however, is that the fans must work against a higher pressure difference all the time. Hence, the optimum bed length will incorporate a fraction of storage material which does not cycle through the full temperature swing of the bulk of the material.

Based upon the results of recent research work not yet published, the optimum was found at a bed design incorporating between 15 and 20 percent more material than would be required to store the energy available. This system required a parasitic power of 1 percent of the energy stored and operated at a round trip efficiency of 80 percent. These are felt to be typically achievable values.

4.0 CONCLUSIONS

Thermal energy storage systems have been analyzed for each of the five temperature spans identified. The estimated round trip efficiencies and parasitic power requirements for these systems are collected in Table IV-53.

Table IV-53
ESTIMATED STORAGE SYSTEM PARASITIC LOSSES AND EFFICIENCY,
AS A FUNCTION OF STORAGE TEMPERATURE RANGE

<u>Bin No.</u>	<u>Temperature Range (°F)</u>	<u>Parasitic Power (Ratioed to Energy Stored)</u>	<u>Round Trip Efficiency (%)</u>
1	140-212	2.7×10^{-4}	98
2	212-300	0	95
3	300-500	0	85
4	500-700	0	70
5	700-1,000	0.02	80

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D. BALANCE OF PLANT SYSTEMS

INTRODUCTION

Section D contains descriptions of the following fourteen balance of plant systems:

<u>SYSTEM NUMBER</u>	<u>SYSTEM NAME</u>
1	Distillate oil storage and distribution system
2	Residual oil storage and distribution system
3	Coal storage and distribution system
4	Limestone storage and distribution system
5	Dry waste solids disposal system
6	Wet waste solids disposal system
7	Sulfur dioxide scrubber system
8	Hot gas cleanup system
9	Boiler feedwater system
10	Heat rejection system
11	Electrical conditioning and control system
12	Energy conversion system building
13	Site preparation and development
14	Energy conversion equipment installation

A descriptive section follows for each balance of plant system including characteristics and, where appropriate, a diagram of the system. Data are given as a function of system capacity. The range of capacity considered was chosen to bracket the systems expected to be required by the CTAS cogeneration plants.

Curves of the field construction cost variation with system capacity are included for each balance of plant system, 1 through 11. The costs are broken down into equipment and materials and installation costs. Detailed breakdowns of the cost of systems for design capacity are also provided for systems 1 through 11.

Operating and Maintenance Costs

The annual operating and maintenance costs for the cogeneration facility balance of plant can best be related to the type and size of heat source used in the plant. The annual costs in dollars per million Btu/hr of design thermal output capacity of the heat source are as follow:

<u>Type of Plant</u>	<u>Annual O&M Costs</u> <u>Dollars/Million Btu/Hr</u>
Oil-fired heat source	117
Coal-fired heat source	204
Coal-fired heat source with sulfur dioxide scrubber	554
Coal-fired heat source with hot gas cleanup system	258

SYSTEM 1
DISTILLATE OIL STORAGE AND DISTRIBUTION SYSTEM

The distillate oil storage and distribution system is shown schematically in Figure IV-54. The system includes provisions for the unloading, storage, and the distribution to the heat source burner of petroleum or coal derived distillate fuel. The storage system is sized for a thirty day capacity. Design and operating characteristics for distillate oil systems providing a fuel flow equivalent to 50 million to 1200 million Btu/hr are outlined below.

Characteristics

- Fuel 65F unloading, transfer, and delivery temperature
2.5 centistokes viscosity at 100F
- Tanks 30 day storage tank capacity
24 hour day tank capacity
Carbon steel construction
4 in. fiberglass insulation
- Unloading Pumps Capacity to unload 48 hours of burner fuel in four hours or less
- Transfer Pumps Capacity to fill the day tank in four hours or less
- Booster Pump Capacity designed for maximum burner fuel consumption
- Piping Nominal pipe lengths are included for all services.

Number of Units of Major Equipment Items

<u>Item</u>	<u>Fuel Heat Rate Million Btu/hr</u>	<u>Number of Operating Units</u>
Storage Tanks	<500	1
	500 - 1000	2
	>1000	3
Day Tank	<100	0
	>100	1
Unloading Pumps	<100	1
	100 - 1000	4
	>1000	8

Number of Units of Major Equipment Items (Cont'd.)

<u>Item</u>	<u>Fuel Heat Rate Million Btu/hr</u>	<u>Number of Operating Units</u>
Transfer Pumps	<1000	1
	>1000	2
Booster Pump	All Sizes	1

Utility Requirements

Electric power is required for the unloading, transfer, and booster pumps. The auxiliary power requirement is 0.009 kWe per million Btu/hr of fuel energy delivered.

Capital Costs

Figure IV-55 shows the field construction cost as a function of the heat content of the fuel flow. The cost breakdown for the design point fuel flow equivalent to 500 million Btu/hr is presented in Table IV-54.

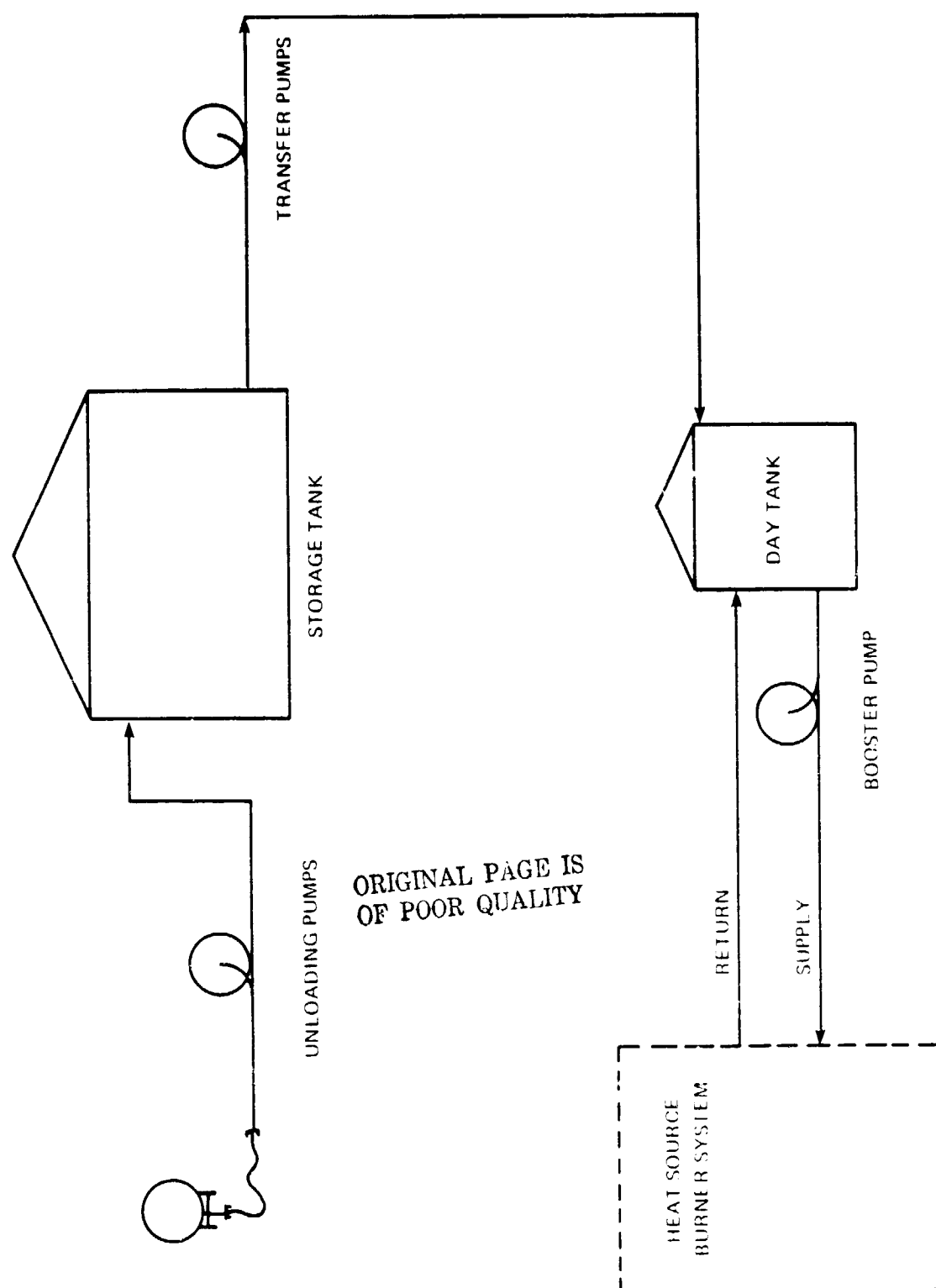


Figure IV-54 1-1 DISTILLATE OIL STORAGE AND DISTRIBUTION SYSTEM

COST IN MID-1978 DOLLARS

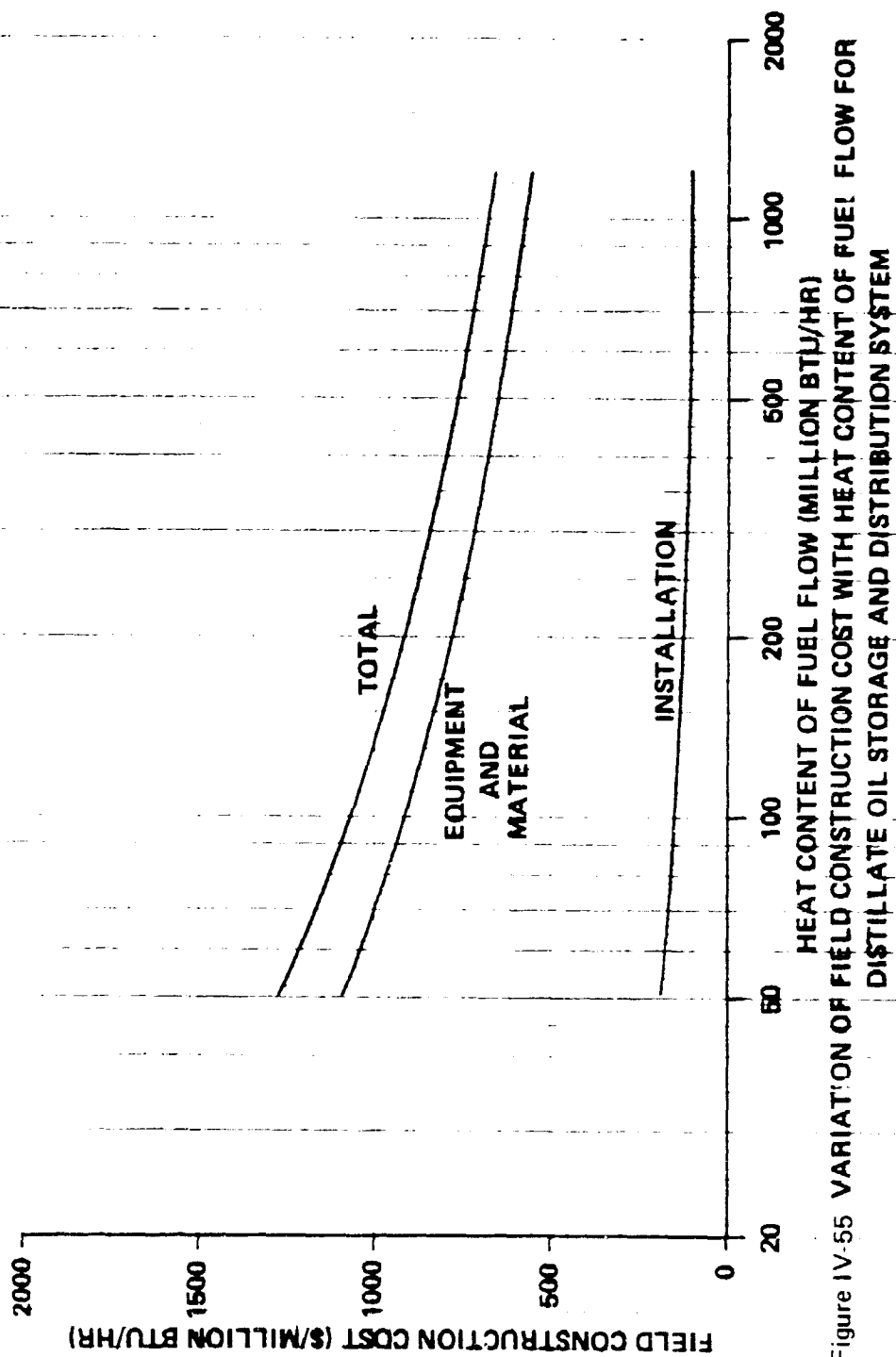


Figure IV-55 VARIATION OF FIELD CONSTRUCTION COST WITH HEAT CONTENT OF FUEL FLOW FOR DISTILLATE OIL STORAGE AND DISTRIBUTION SYSTEM

TABLE IV-54
DISTILLATE OIL STORAGE AND DISTRIBUTION SYSTEM
FIELD CONSTRUCTION COST
(FUEL FLOW EQUIVALENT TO 500 MILLION BTU/HR)

<u>ITEMS</u>	<u>DOLLARS</u>
Equipment	
Tanks	221,000
Pumps	21,000
Other	8,000
Civil/Structural	56,000
Piping/Instrumentation	<u>20,000</u>
Total Equipment and Materials	326,000
Direct Installation Labor (@ \$14/MH)	33,000
Indirects (@ 75% of Direct Labor)	<u>25,000</u>
Total Field Construction Cost (Mid-1978 Dollars)	384,000 =====

SYSTEM 2 RESIDUAL OIL STORAGE AND DISTRIBUTION SYSTEM

The residual oil storage and distribution system shown schematically in Figure IV-56 includes provisions for unloading, storage, and distribution to the heat source system of petroleum or coal derived residual fuel. The storage system is sized for a thirty day capacity. Design and operating characteristics for system providing fuel flows equivalent to 50 to 1200 million Btu/hr are as follows.

Characteristics

- Fuel
 - 100F unloading temperature
 - 150F circulating temperature
 - 40 centistokes viscosity at 100F
- Tanks
 - 30 day storage tank capacity
 - 24 hour day tank capacity
 - Carbon steel construction
 - 4 in fiberglass insulation
- Unloading Pumps
 - Capacity to unload 48 hours of burner fuel in four hours or less
- Circulation Pump Rates
 - 10:1 for <100 million Btu/hr of delivered fuel energy
 - 5:1 for 100 million to 500 million Btu/hr of delivered fuel energy
 - 2:1 for >500 million Btu/hr of delivered fuel energy
- Booster Pumps
 - Capacity designed for maximum burner consumption
- Heaters
 - Steam heating provided to maintain specified operating temperatures
- Piping
 - Nominal pipe lengths are included for all services.

Number of Units of Major Equipment Items

<u>Item</u>	<u>Fuel Heat Rate Million Btu/hr</u>	<u>Number of Operating Units</u>
Storage Tanks	<500	1
	500 - 1000	2
	>1000	3

Number of Units of Major Equipment Items (Cont'd.)

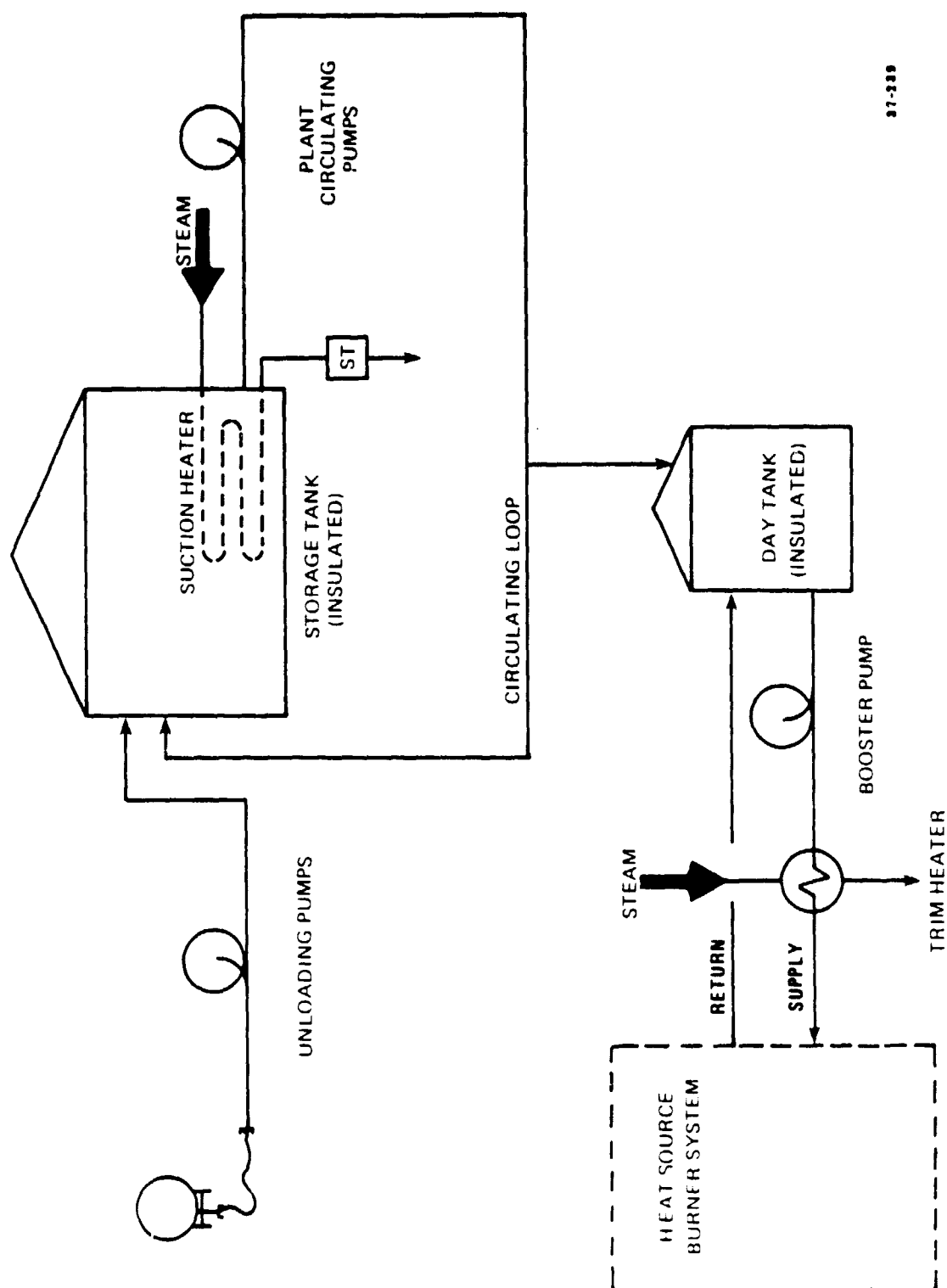
<u>Item</u>	<u>Fuel Heat Rate Million Btu/hr</u>	<u>Number of Operating Units</u>
Day Tank	<100	0
	>100	1
Unloading Pumps	<100	1
	100 - 1000	4
	>1000	8
Circulating Pumps	>1000	1
	>1000	2
Booster Pump	All Sizes	1
Circulating Pump Suction Heater	All Sizes	1
Train Heater	All Sizes	1

Utility Requirements

- Electric power is required for the system pumps. The power required is 0.2 kWe per million Btu/hr of delivered fuel energy
- Low pressure, 300F steam is required for the system heaters. The steam energy required is 7000 Btu/hr per million Btu/hr of delivered fuel energy.

Capital Costs

Figure IV-57 shows the field construction cost as a function of the heat content of the fuel flow. The cost breakdown for the design point fuel flow equivalent to 500 million Btu/hr is presented in Table IV-55.



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Figure IV-56 RESIDUAL OIL STORAGE AND DISTRIBUTION SYSTEM

COST IN MID-1978 DOLLARS

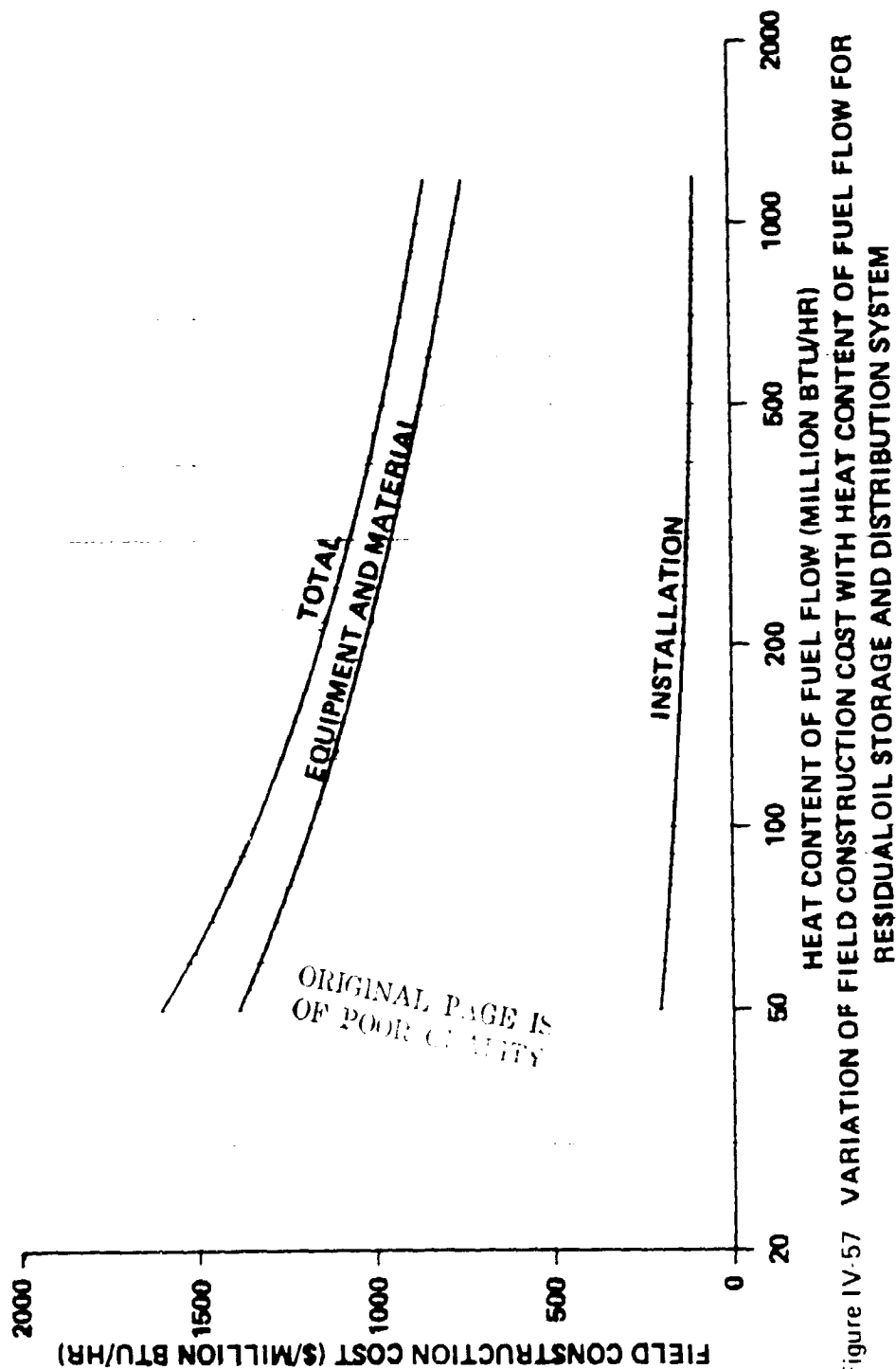


Figure IV-57 VARIATION OF FIELD CONSTRUCTION COST WITH HEAT CONTENT OF FUEL FLOW FOR RESIDUAL OIL STORAGE AND DISTRIBUTION SYSTEM

TABLE IV-55

RESIDUAL OIL STORAGE AND DISTRIBUTION SYSTEM

FIELD CONSTRUCTION COST

(FUEL FLOW EQUIVALENT TO 500 MILLION BTU/HR)

<u>ITEMS</u>	<u>DOLLARS</u>
Equipment	
Tanks	316,000
Heaters	8,000
Pumps	21,000
Other	8,000
Civil/Structural	56,000
Piping/Instrumentation	<u>23,000</u>
Total Equipment and Materials	432,000
Direct Installation Labor (@ \$14/MH)	33,000
Indirects (@ 75% of Direct Labor)	<u>25,000</u>
Total Field Construction Cost (Mid-1978 Dollars)	490,000 =====

SYSTEM 3
COAL STORAGE AND DISTRIBUTION SYSTEM

The coal storage and distribution system is illustrated in Figure IV-58. It includes provisions for coal unloading, stockpiling, crushing and day storage prior to conveying to the heat source. Design and operating characteristics of the coal systems providing fuel flows equivalent to 50 million to 1200 million Btu/hr are summarized below.

Characteristics

- Trackhoppers and unloading apron feeders located at trackside
- Stacking conveyor with stacker
- Stockpile for 30 day live storage
- Reclaim feeder
- Transfer conveyor
- Double roll crusher
- Crushed coal conveyor and day bin conveyors
- Carbon steel day bins
- Belt type weigh feeders
- Includes foundations, structural steel, conveyor supports, platforms and walkways
- Dust collection system and fire safety system.

Number of Units of Major Equipment Items

<u>Item</u>	<u>Fuel Heat Rate Million Btu/hr</u>	<u>Number of Operating Units</u>
Trackhoppers and Apron Feeders	All Sizes	1 Lot
Stacking Conveyor and Stacker	All Sizes	1 Lot
Stockpile	All Sizes	1 Lot

Number of Units of Major Equipment Items (Cont'd.)

<u>Item</u>	<u>Fuel Heat Rate Million Btu/hr</u>	<u>Number of Operating Units</u>
Reclaim Feeder	50-600	1
	600-1200	2
Transfer Conveyor	50-600	1
	600-1200	2
Double Roll Crushers	50-600	1
	600-1200	2
Crushed Coal Conveyor	50-600	1
	600-1200	2
Day Bin Conveyors	50-150	1
	150-400	2
	400-700	3
	700-1000	4
	1000-1200	5
Day Bins	50-150	1
	150-400	2
	400-700	3
	700-1000	4
	1000-1200	5
Belt Type Weigh Feeder	50-150	1
	150-400	2
	400-700	3
	700-1000	4
	1000-1200	5

Utility Requirements

- The electric power requirement for all drives in the system is 0.07 kWe per million Btu/hr of delivered fuel energy

Capital Costs

Figure IV-59 shows the field construction cost as a function of the heat content of the fuel flow. The cost breakdown for the design point fuel flow equivalent to 500 million Btu/hr is presented in Table IV-56.

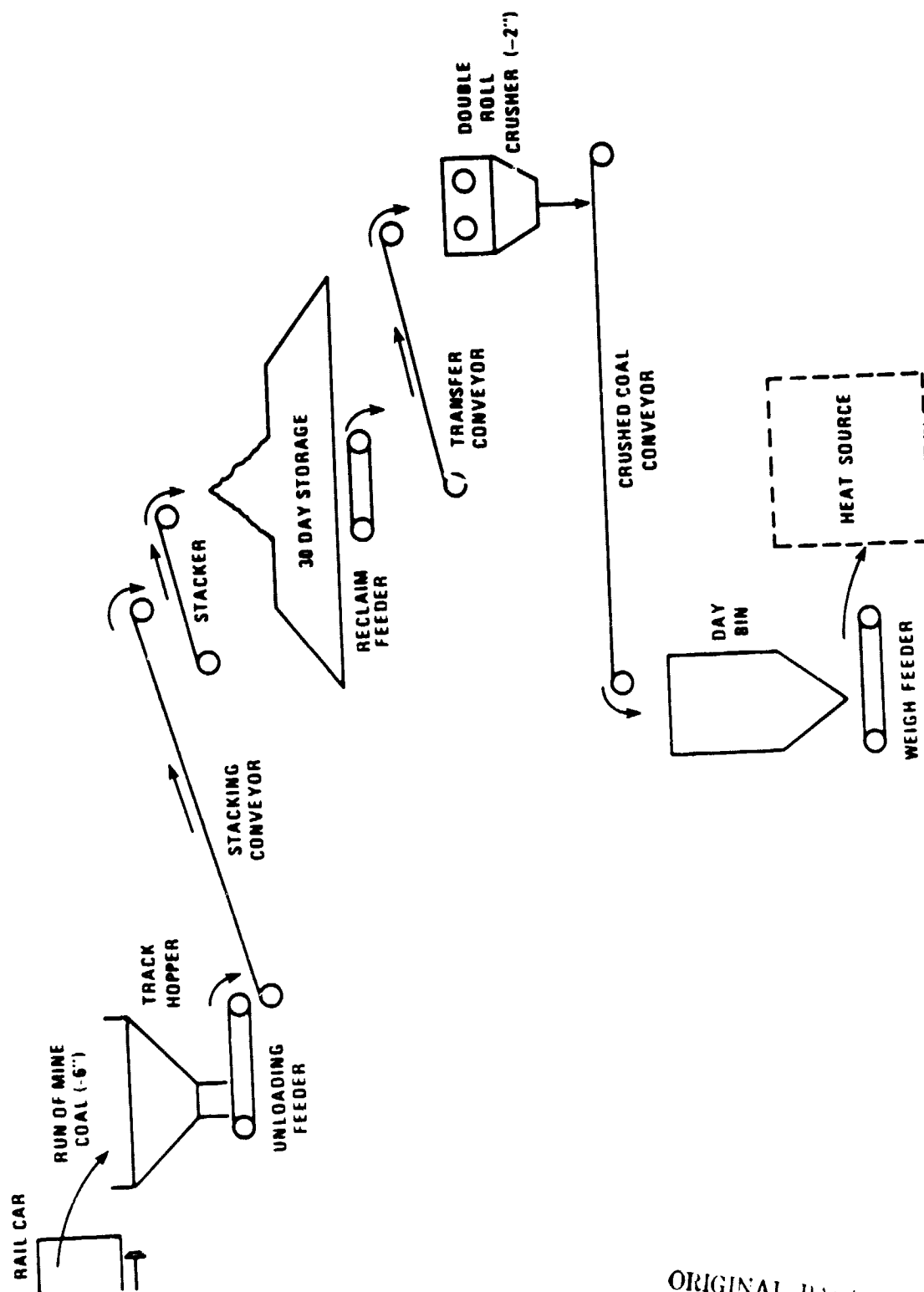


FIGURE IV-58 COAL STORAGE AND DISTRIBUTION SYSTEM

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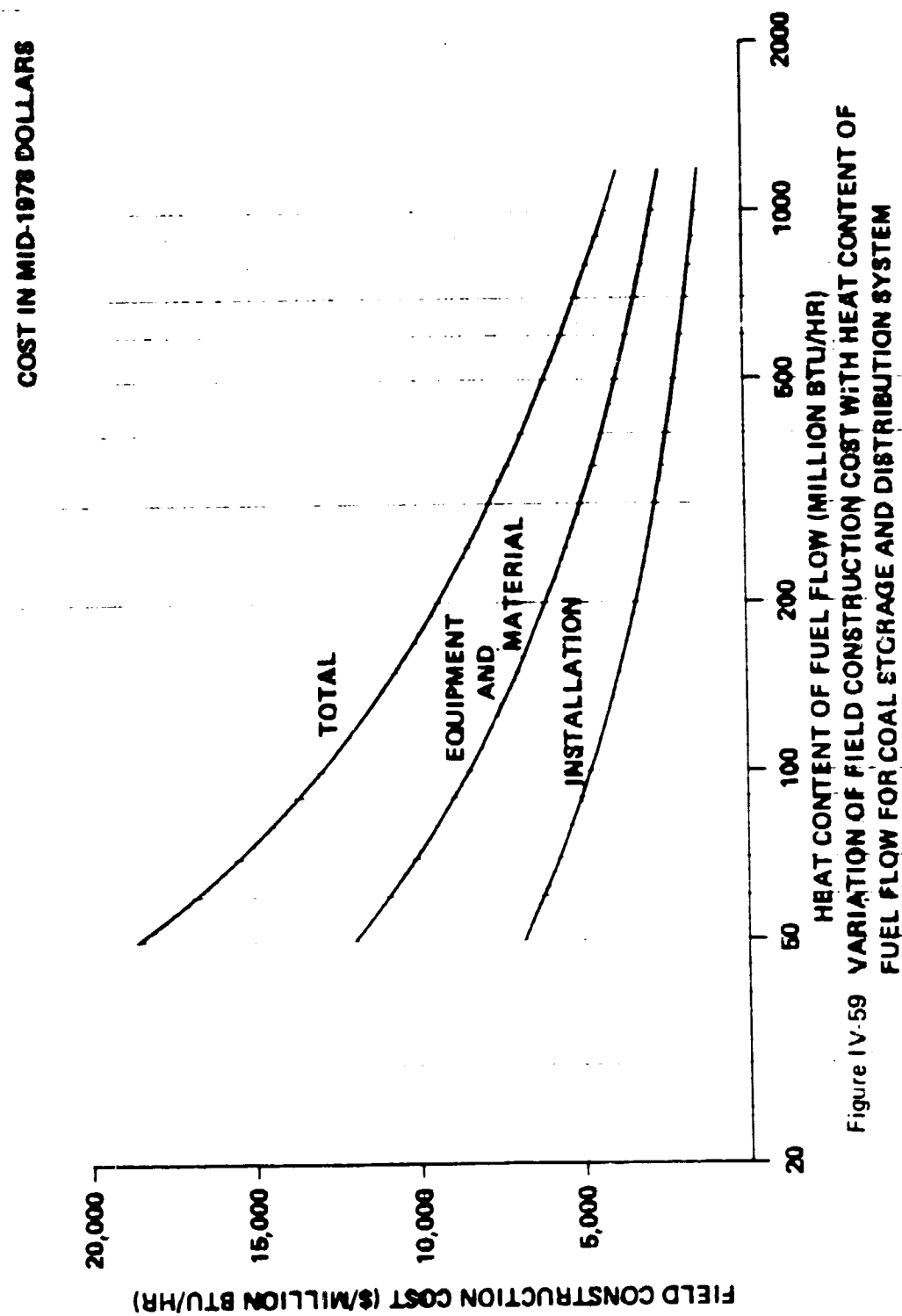


Figure IV-59 VARIATION OF FIELD CONSTRUCTION COST WITH HEAT CONTENT OF FUEL FLOW FOR COAL STORAGE AND DISTRIBUTION SYSTEM

TABLE IV-56
COAL STORAGE AND DISTRIBUTION SYSTEM
FIELD CONSTRUCTION COST
(FUEL FLOW EQUIVALENT TO 500 MILLION BTU/HR)

<u>ITEMS</u>	<u>DOLLARS</u>
Equipment	
Bins	95,000
Conveyors and Feeders	701,000
Other	586,000
Civil/Structural	300,000
Piping/Instrumentation	<u>223,000</u>
Total Equipment and Materials	1,905,000
Direct Installation Labor (@ \$14/MH)	595,000
Indirects (± 75% of Direct Labor)	<u>446,000</u>
Total Field Construction Cost (Mid-1978 Dollars)	2,946,000 =====

SYSTEM 4
LIMESTONE STORAGE AND DISTRIBUTION SYSTEM

The limestone storage and distribution system is illustrated in Figure IV-60. It includes provisions for stockpiling, transfer to day bins, and conveying to the heat source. It is assumed that unloading equipment used for coal handling will be used for unloading the limestone. Design and operating characteristics of limestone systems providing 2000 to 60,000 lb/hr of stone are summarized below. It is also assumed that the system required for handling dolomite is similar to the limestone handling system.

Characteristics

- Stockpile for 30 day live storage
- Reclaim feeder
- Transfer conveyor and day bin conveyors
- Carbon steel day bins
- Belt type weigh feeder
- Includes foundations, structural steel, conveyor supports, platforms and walkways
- Dust collection equipment.

Number of Units of Major Equipment Items

<u>Item</u>	<u>Fuel Heat Rate Million Btu/hr</u>	<u>Number of Operating Units</u>
Stockpile	All Sizes	1 Lot
Reclaim Feeder	2-25	1
	25-60	2
Transfer Conveyor	2-25	1
	25-60	2
Day Bin Conveyors	2-25	1
	25-60	1

Number of Units of Major Equipment Items (Cont'd.)

<u>Item</u>	<u>Fuel Heat Rate Million Btu/hr</u>	<u>Number of Operating Units</u>
Day Bins	2-25	1
	25-60	2
Belt Type Weigh Feeder	2-25	1
	25-60	2

Utility Requirement

- The electric power requirement for all drives in the system is 0.45 kWe per thousand lb/hr of limestone supplied by the system.

Capital Cost

Figure IV-61 shows the field construction cost as a function of system capacity. The cost breakdown for the design point flow of 24,000 lb/hr is presented in Table IV-57.

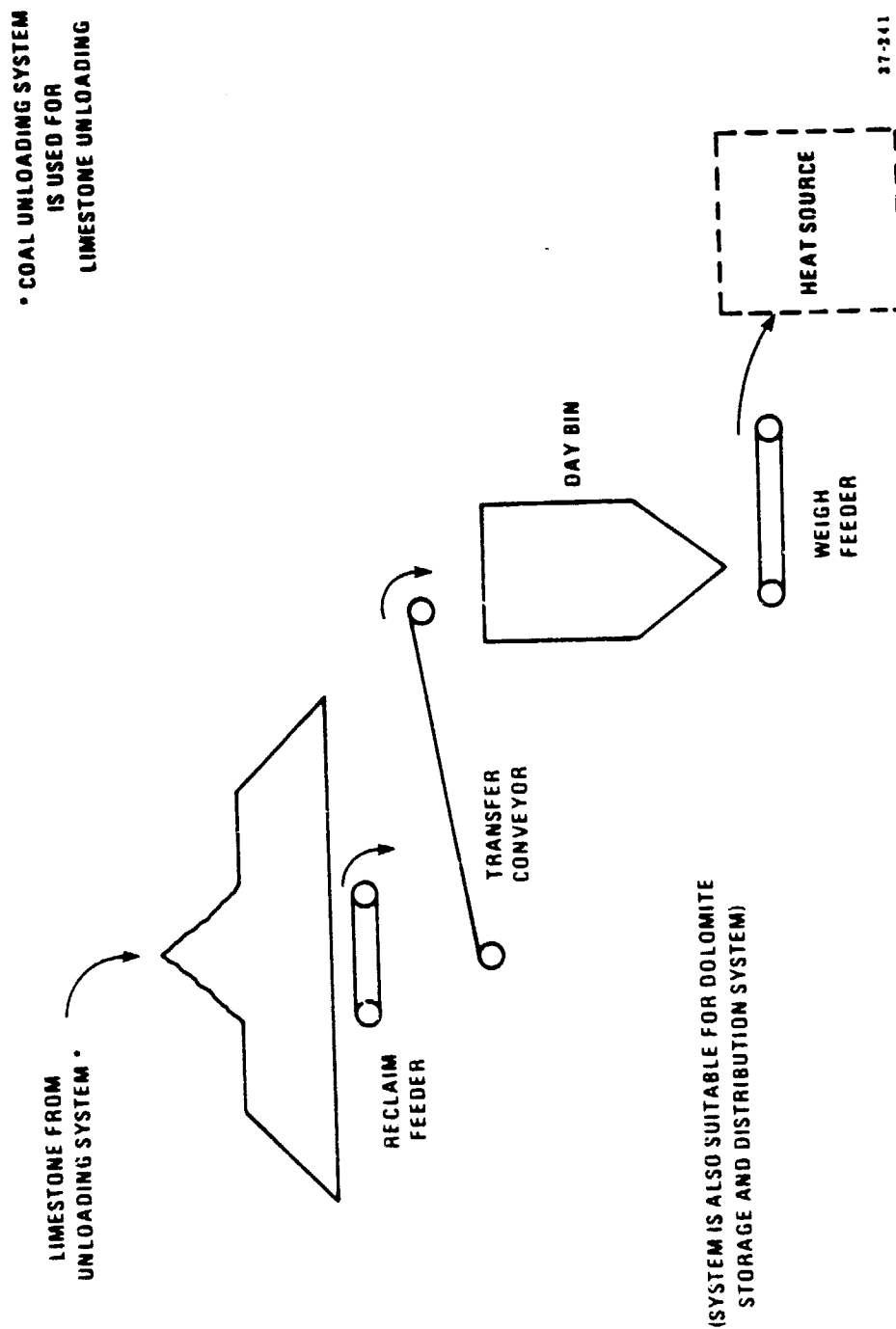


Figure IV-60 LIMESTONE STORAGE AND DISTRIBUTION SYSTEM

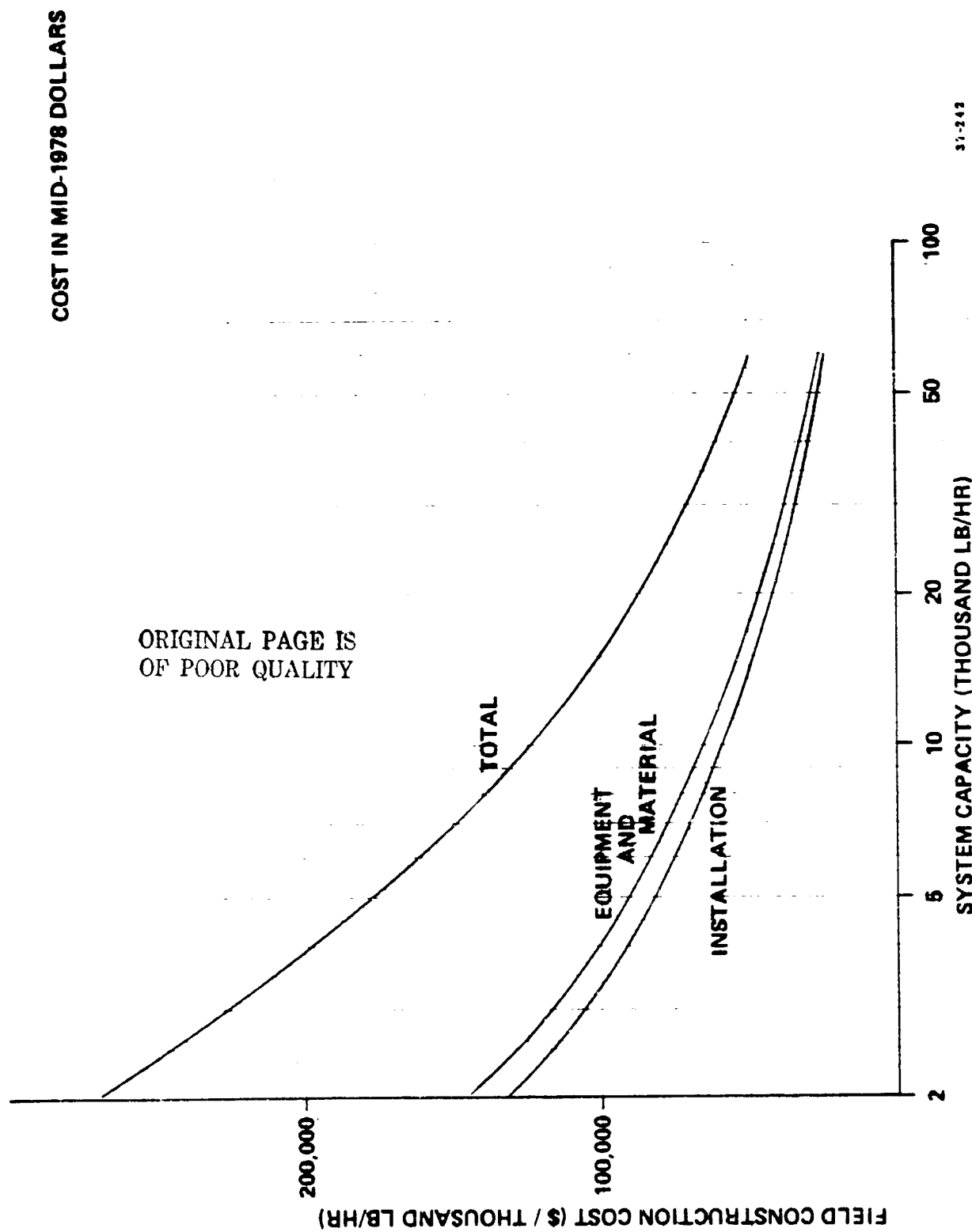


Figure IV-61 VARIATION OF FIELD CONSTRUCTION COST WITH SYSTEM CAPACITY FOR LIMESTONE STORAGE AND DISTRIBUTION SYSTEM.

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TABLE IV-57
LIMESTONE STORAGE AND DISTRIBUTION SYSTEM
FIELD CONSTRUCTION COST
(24,000 LB/HR FLOW)

<u>ITEMS</u>	<u>DOLLARS</u>
Equipment	
Bins	50,000
Conveyors and Feeders	391,000
Other	289,000
Civil/Structural	100,000
Piping/Instrumentation	<u>157,000</u>
Total Equipment and Materials	987,000
Direct Installation Labor (@ \$14/MH)	512,000
Indirects (@ 75% of Direct Labor)	<u>384,000</u>
Total Field Construction Cost (Mid-1978 Dollars)	1,883,000 =====

SYSTEM 5
DRY SOLIDS WASTE DISPOSAL SYSTEM

The dry solids waste disposal system, shown schematically on Figure IV-62, includes provisions for the distribution, storage, and unloading for transport of cold, dry solids waste. The storage system is sized for a one week solids capacity. Design and operating characteristics for waste disposal systems handling 100 to 40,000 lb/hr are summarized below.

Characteristics

- Suitable for dry solid waste, below 350F, from the following systems
 - Atmospheric fluidized bed
 - Pressurized fluidized bed
 - Pulverized coal system cyclone
- 200 ft long transfer conveyor from heat source to bucket elevators
- Carbon steel bucket elevator to carry solids from transfer conveyor to storage bin
- Carbon steel storage bins for one week solids capacity
- 25 ft long loadout conveyor, with personnel protection, for unloading storage bin.

Number of Units of Major Equipment Items

<u>Item</u>	<u>Solids Flow Rate Thousand lb/hr</u>	<u>Number of Operating Units</u>
Transfer Conveyor	<20	1
	>20	2
Bucket Elevator	<20	1
	>20	2
Storage Bins	<10	1
	10 - 20	2
	20 - 30	3
	30 - 40	4
Loadout Conveyor	<20	1
	>20	2

Utility Requirements

Electric power will be required for the transfer conveyor, bucket elevator, and the loadout conveyor. The auxiliary power requirement is approximately 2 kWe per 1000 lb/hr of dry solids waste.

Capital Cost

Figure IV-63 shows the field construction cost as a function of system capacity. The cost breakdown for the design point flow of 20,000 lb/hr is presented in Table IV-58.

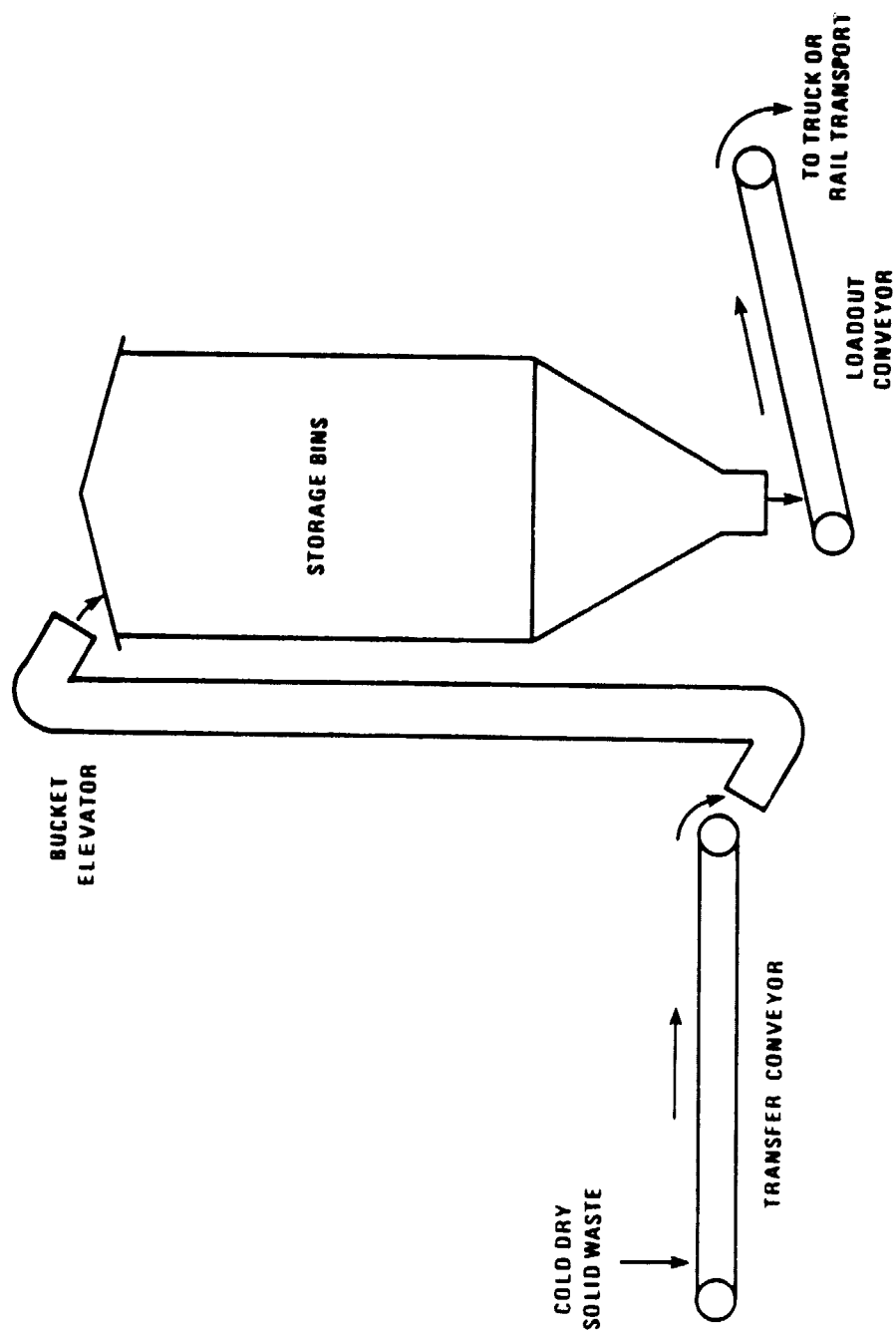


FIGURE IV-62 DRY WASTE SOLIDS DISPOSAL SYSTEM

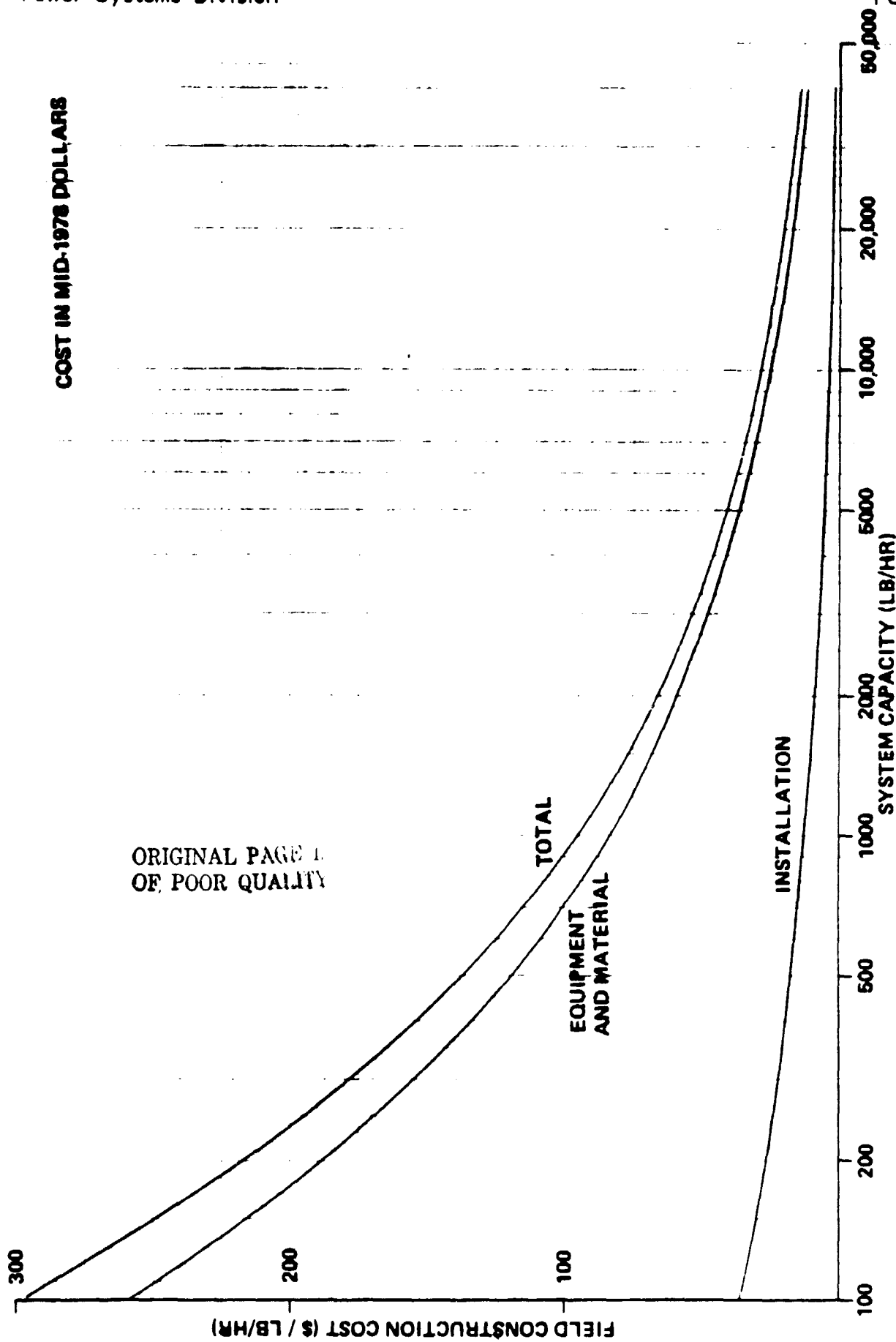


Figure IV-63 VARIATION OF FIELD CONSTRUCTION COST WITH SYSTEM CAPACITY FOR DRY WASTE SOLIDS DISPOSAL SYSTEM.

TABLE IV-58
DRY WASTE SOLIDS DISPOSAL SYSTEM
FIELD CONSTRUCTION COST
(20,000 LB/HR FLOW)

<u>ITEMS</u>	<u>DOLLARS</u>
Equipment	
Bins	80,000
Conveyors	68,000
Dust Collector	110,000
Other	30,000
Civil/Structural	50,000
Piping/Instrumentation	<u>28,000</u>
Total Equipment and Materials	366,000
Direct Installation Labor (@ \$14/MH)	33,000
Indirects (@ 75% of Direct Labor)	<u>25,000</u>
Total Field Construction Cost (Mid-1978 Dollars)	424,000 =====

**SYSTEM 6
WET WASTE SOLIDS DISPOSAL SYSTEM**

The wet waste solids disposal system is illustrated schematically in Figure IV-64. The system includes provisions for forming a solids waste slurry, slurry clarification, sludge filtration, water reclamation, and sludge disposal. Design and operating characteristics for systems handling 10 to 2000 lb/hr of wet waste solids are summarized below.

Characteristics

- The system is suitable for solid wastes above 350F from the following sources:
 - Coal fired boiler bottom ash
 - Hot gas cleanup system
- Carbon steel slurry tank with corrosion resistance coating and an integral clinker grinder
- Settling pond with 4 in. thick concrete and 30 mil thick polyethylene liner
- Carbon steel reclaim water holding tank with corrosion resistance coating
- Solid waste dump area for intermittent truck loading and the trucks
- Slurry pump and sluicing water supply pump
- Filter press and filter feed pump
- Nominal pipe lengths included for all services.

Number of Units of Major Equipment Items

For all of the sizes of solids disposal system considered in this study, there will be one operating unit of each major equipment item.

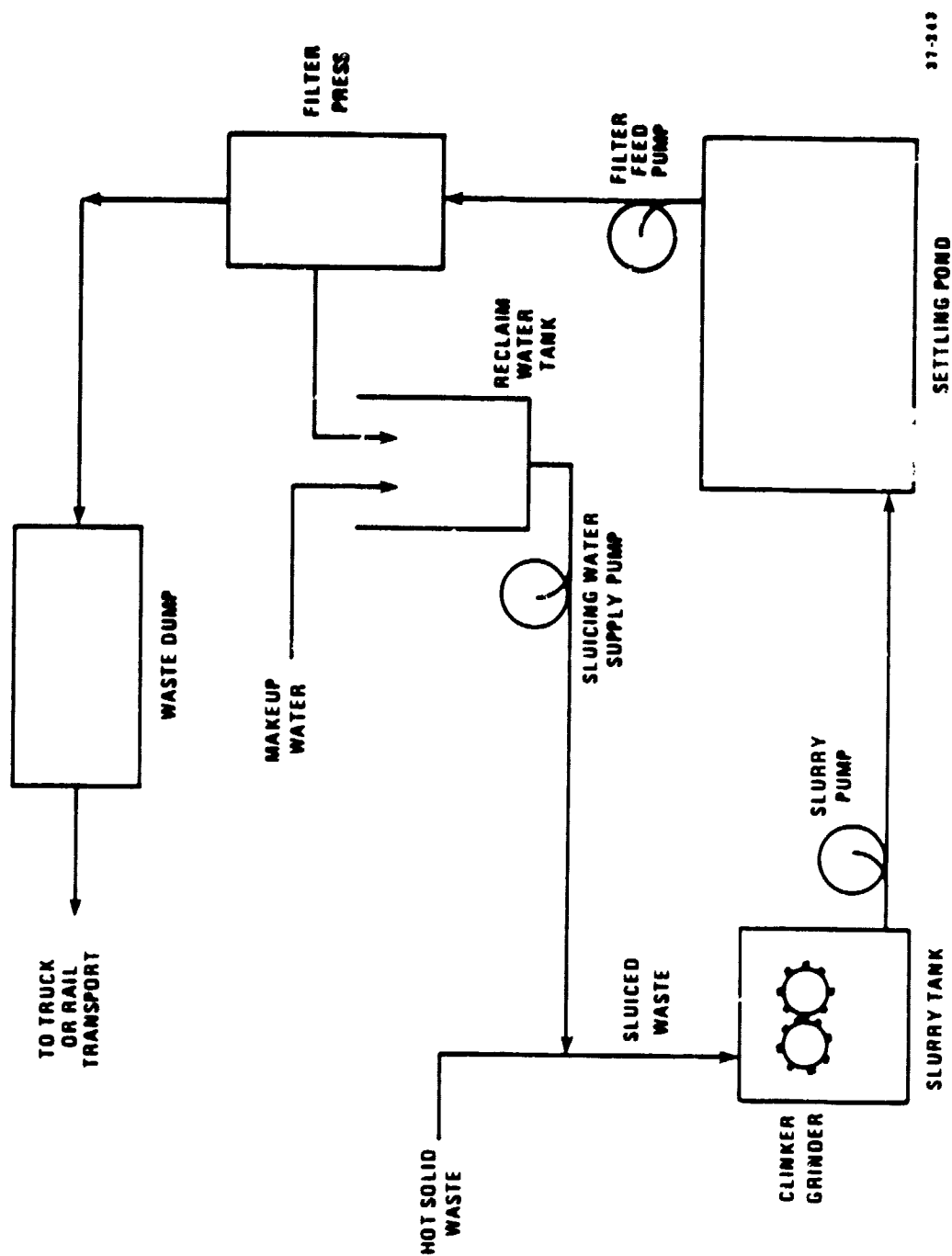
Utility Requirements

- Electric power is required for pumps. The power requirement is 0.005 kWe per lb/hr of solid waste handled.

- Makeup water required is 0.5 lb. per lb/hr of solid waste handled.

Capital Cost

Figure IV-65 shows the field construction cost as a function of system capacity. The cost breakdown for the design point flow of 1,000 lb/hr is presented in Table IV-59.



37-349

Figure IV-64 WET WASTE SOLIDS DISPOSAL SYSTEM

COST IN MID-1978 DOLLARS

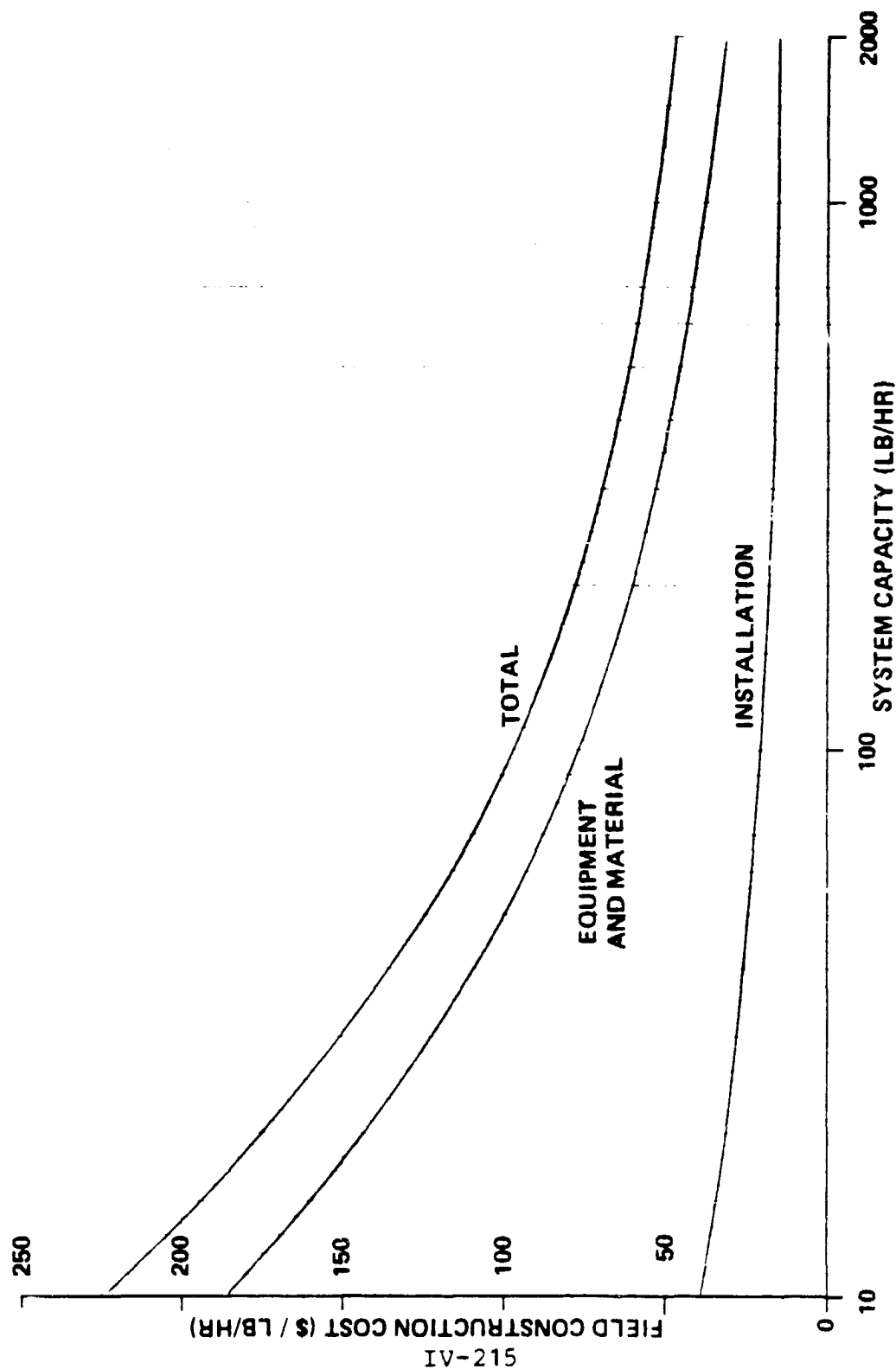


Figure IV-65 VARIATION OF FIELD CONSTRUCTION COST WITH SYSTEM CAPACITY FOR WET WASTE SOLIDS DISPOSAL SYSTEM

TABLE IV-59
WET WASTE SOLIDS DISPOSAL SYSTEMS
FIELD CONSTRUCTION COST
(1,000 LB/HR FLOW)

<u>ITEMS</u>	<u>DOLLARS</u>
Equipment	
Tanks	13,000
Pumps	8,000
Other	2,000
Civil/Structural	10,000
Piping/Instrumentation	<u>5,000</u>
Total Equipment and Materials	38,000
Direct Installation Labor (@ \$14/MH)	9,000
Indirects (@ 75% of Direct Labor)	<u>7,000</u>
Total Field Construction Cost (Mid-1978 Dollars)	54,000 =====

SYSTEM 7
SULFUR DIOXIDE SCRUBBER SYSTEM

The sulfur dioxide scrubber system is illustrated schematically in Figure IV-66. It includes provisions for removing the sulfur from the flue gas, heating the clean flue gas, and disposing of the waste solids. Design and operating characteristics for sulfur dioxide scrubber systems operating with a heat sources firing 50 million to 1200 million Btu/hr of fuel are summerized below.

Characteristics

- Lime/limestone or lime/soda ash sulfur dioxide scrubber
- Sulfur dioxide concentration in the heat source flue gas is 3000 ppm. With a scrubber efficiency of 85 percent, the concentration in the clean flue gas to the stack is 450 ppm. The system also removes 20 to 25 percent of the total particulate matter
- Sulfur dioxide emission in clean flue gas is 1.2 lb. of sulfur per million input Btu/hr
- The scrubber system also includes the reagent system, thickener, filter, and associated pumps and piping
- The flue gas reheat system furnishes 225F clean air for mixing with 125F scrubbed flue gas to achieve 175F mixture temperature at the stack entrance. The following equipment capacities are required:
 - 250 cfm per million input Btu/hr dilution air fan capacity
 - 42 ft² per million input Btu/hr air heat exchanger area
- Solid waste disposal rate of 11 lb (dry) per million input Btu/hr
- Trucks for hauling, and truck loading facility.

Number of Units of Major Equipment Items

Sulfur dioxide removal system operating with a heat source energy input of 50 million to 1200 million Btu/hr require only a single unit of each major equipment item.

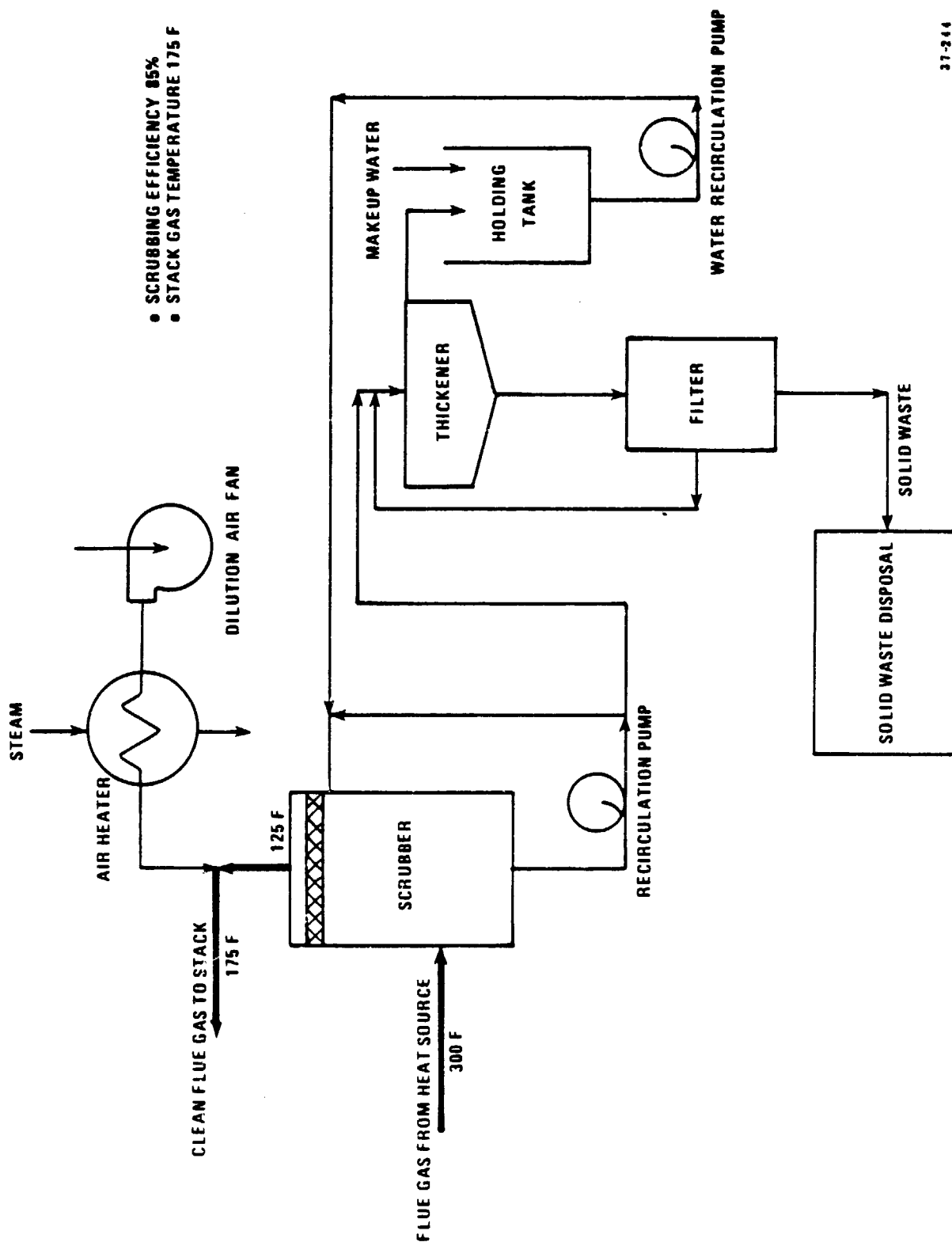
Utility Requirements

The following utilities and operating materials, per million input Btu/hr of fuel fired, are required for the scrubber system:

- 0.2 kWe of auxiliary electric power
- 50,000 Btu of steam for air heating
- 0.2 gal/min of makeup water
- 6 lb of lime as CaO
- 0.5 lb of soda ash as Na₂CO₃.

Capital Cost

Figure IV-67 shows the field construction cost as a function of heat content of fuel consumed. The cost breakdown for the design point heat input of 500 million Btu/hr is presented in Table IV-60.



37-244

FIGURE IV-66 SULFUR DIOXIDE SCRUBBER SYSTEM

COST IN MID-1978 DOLLARS

NOTE: TOTAL COST INCLUDES SUB CONTRACT COST FOR
SCRUBBER SYSTEM PACKAGE AND MISCELLANEOUS
INSTALLATION LABOR OF \$280 PER MILLION BTU/HR

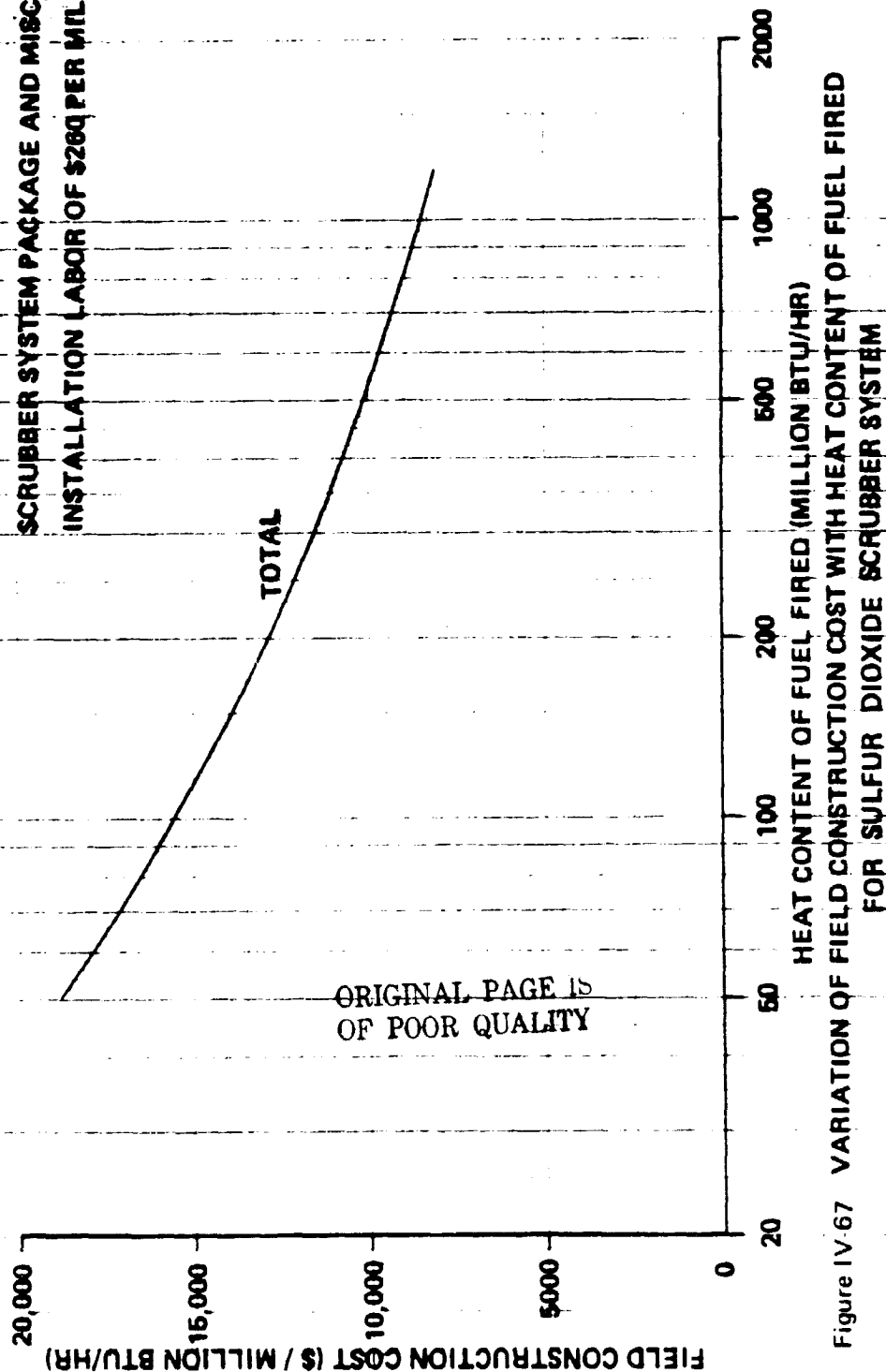


Figure IV-67 VARIATION OF FIELD CONSTRUCTION COST WITH HEAT CONTENT OF FUEL FIRED FOR SULFUR DIOXIDE SCRUBBER SYSTEM

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TABLE IV-60
SULFUR DIOXIDE SCRUBBER SYSTEM
FIELD CONSTRUCTION COST
(500 MILLION LB/HR HEAT INPUT)

<u>ITEMS</u>	<u>DOLLARS</u>
Equipment	
Scrubber Package (Subcontract)	4,620,000
Air Heater and Accessories	248,000
Other	37,000
Civil/Structural	-0-
Piping/Instrumentation	<u>-0-</u>
Total Equipment and Materials	4,905,000
Direct Installation Labor (@ \$14/MH)	74,000
Indirects (@ 75% of Direct Labor)	<u>55,000</u>
Total Field Construction Cost (Mid-1978 Dollars)	5,034,000 =====

SYSTEM 8
HOT GAS CLEANUP SYSTEM

The hot gas cleanup system, shown schematically in Figure IV-68, is a high efficiency particulate removal system for cleaning the high temperature combustion products stream from a pressurized fluidized bed (PFB) before the products are expanded through a gas turbine. The system is designed to operate at 1600F and 200 psia and to remove 99.9% of the particulates in the gas stream. Design and operating characteristics for systems sized for gas flowrates from 50,000 to 1,000,000 lb/hr are as follows.

Characteristics

- Two stage system using multiclone followed by granular bed filter
- Multiclone is a refractory lined carbon steel pressure vessel containing multiple small, high efficiency, cyclones
- Granular bed filter operates continuously using intermittent backflush of individual elements (Ducon configuration)
- Motor driven air compressor provides high pressure air stream for backflush
- Lock hopper removes collected particulate from system; solid waste disposal rate of 0.00091 lb/hr of gas
- Refractory lined, carbon steel pipe is used for hot gas.

Number of Units of Major Equipment Items

<u>Item</u>	<u>Gas Flowrate Thousand lb/hr</u>	<u>Number of Operating Units</u>
Multiclone	All Sizes	1
Granular Bed Filter	<350	1
	350-700	2
	>700	3

Utility Requirements

Electric power is required for the backflush compressor motor. The power requirement is 0.67 kWe per 1,000 lb/hr of gas flow.

Capital Costs

Figure IV-69 shows the field construction cost as a function of gas flow rate. The cost breakdown for the design point gas flow of 272,000 lb/hr is presented in Table IV-61.

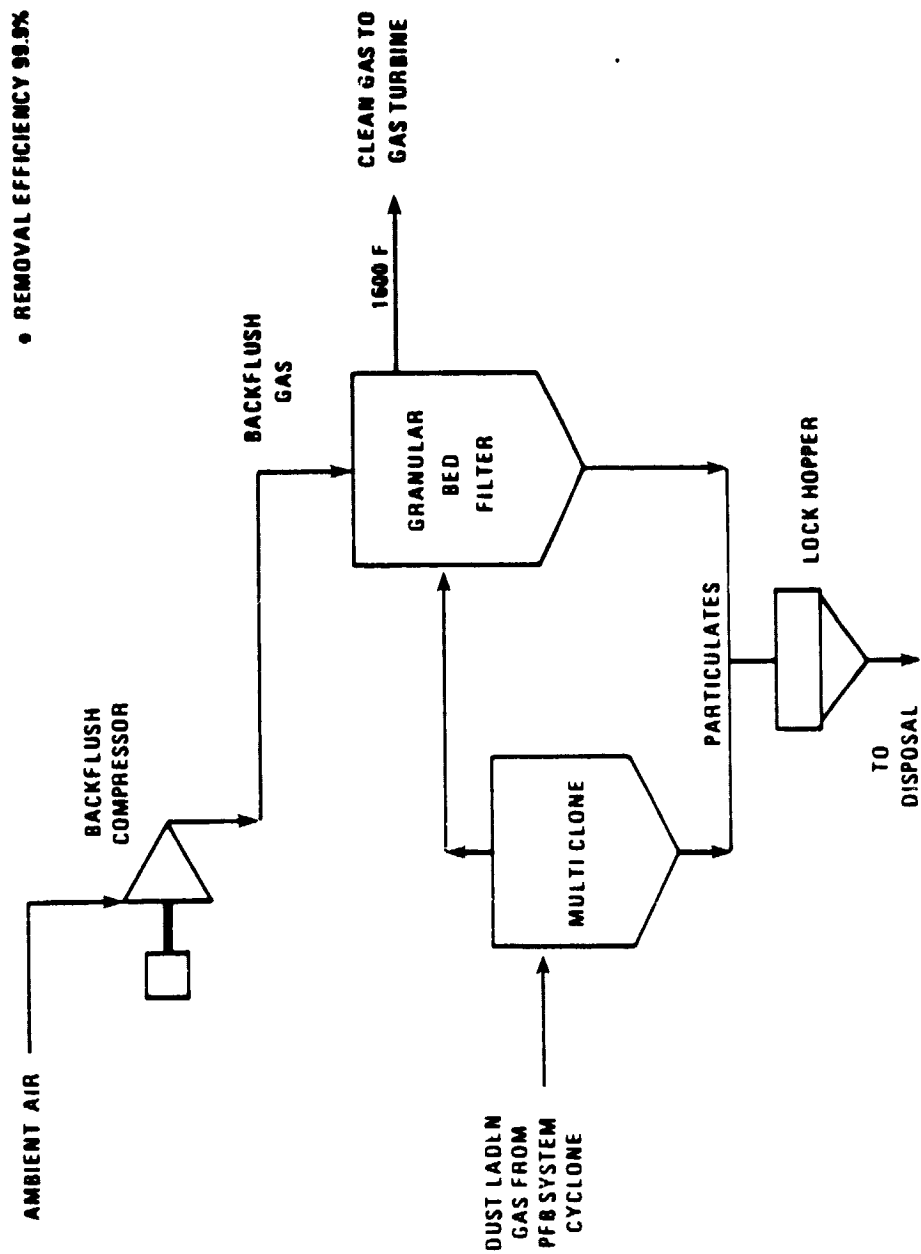


FIGURE IV-68 HOT GAS CLEANUP SYSTEM

COST IN MID-1978 DOLLARS

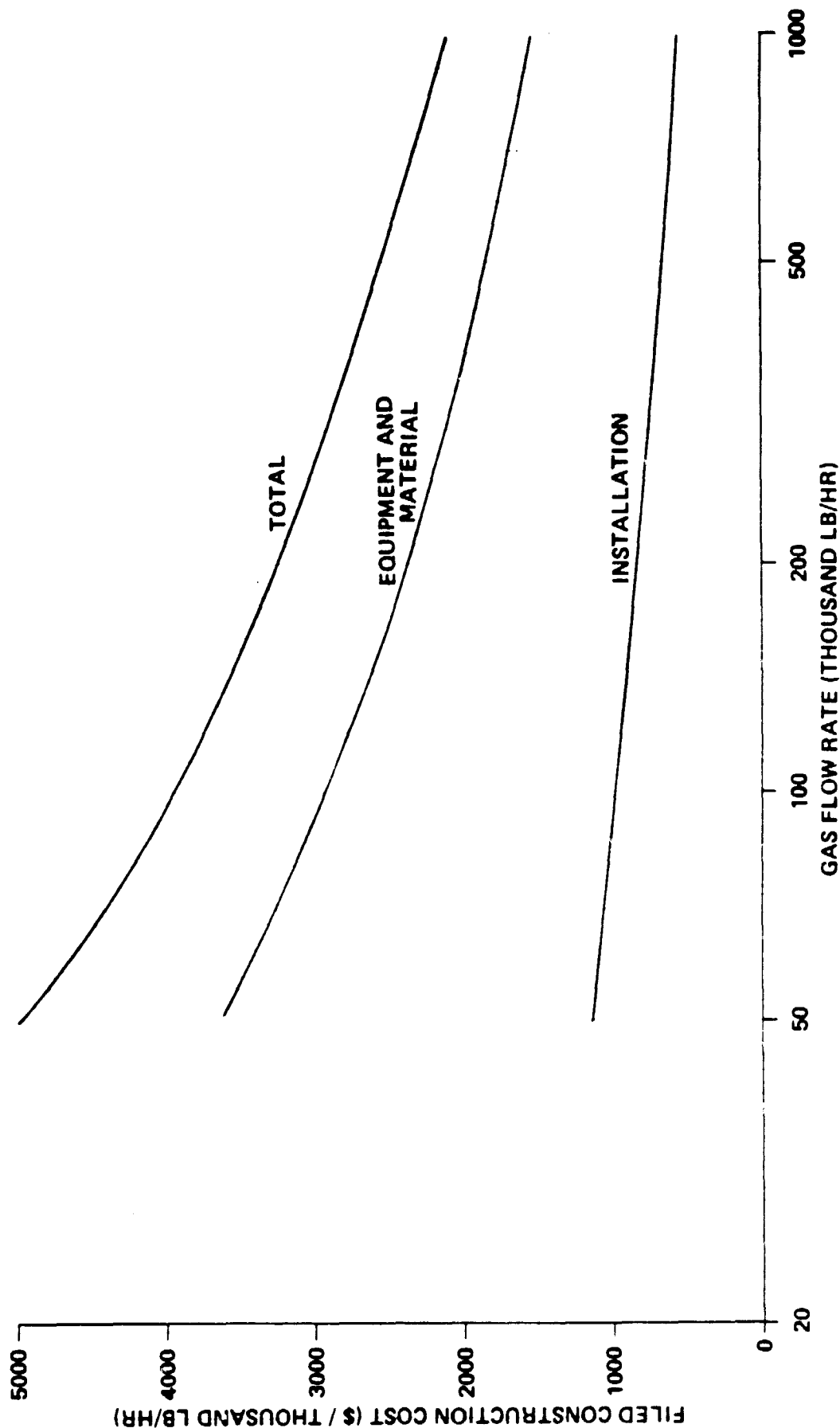


Figure IV.69 VARIATION OF FIELD CONSTRUCTION COST WITH GAS FLOW RATE FOR HOT GAS CLEANUP SYSTEM

TABLE IV-61
HOT GAS CLEANUP SYSTEM
FIELD CONSTRUCTION COST
(272,000 LB/HR GAS FLOW)

<u>ITEMS</u>	<u>DOLLARS</u>
Equipment	
Multiclone	225,000
Granular Bed Filter	200,000
Other	76,000
Civil/Structural	78,000
Piping/Instrumentation	<u>14,000</u>
Total Equipment and Materials	593,000
Direct Installation Labor (@ \$14/MH)	122,000
Indirects (@ 75% of Direct Labor)	<u>92,000</u>
Total Field Construction Cost (Mid-1978 Dollars)	807,000 =====

SYSTEM 9 BOILER FEEDWATER SYSTEM

The feedwater system shown in Figure IV-70 supplies oxygen free, saturated water at 250F for cogeneration and noncogeneration steam generators. The system includes makeup water treatment, feedwater storage, and deaeration. Design and operating characteristics for the system providing boiler feedwater flow of 50,000 lb/hr to 1,000,000 lb/hr are as follows.

Characteristics

- Tray type deaerating feedwater heater operating with 10 minute storage capacity; 15 psig operating pressure (10 psig operating pressure for use with waste heat boiler, case 14 of heat source design)
- Epoxy lined, carbon steel storage tank sized for 10 hour capacity
- Deaerator feed pump
- Mixed bed demineralizer makeup water treatment system sized for 10% makeup
- Includes foundations, structural steel and nominal piping for all services.

Number of Units of Major Equipment Items

Systems with output capacities of 50,000 to 1,000,000 lb/hr of feedwater require only a single unit of each major equipment item.

Utility Requirements

- Electric power requirement for the system equipment is 5.4 kWe per 100,000 lb/hr of feedwater output capacity
- Steam requirement for feedwater heating is 0.11 pound of 300F steam per pound of feedwater when operating at 15 psig and 0.1 pound of 300F steam when operating at 10 psig
- Makeup water required is 10% of the feedwater output capacity.

Capital Cost

Figure IV-71 shows the field construction cost as a function of system capacity. The cost breakdown for the design point feedwater flow of 500,000 lb/hr is presented in Table IV-62.

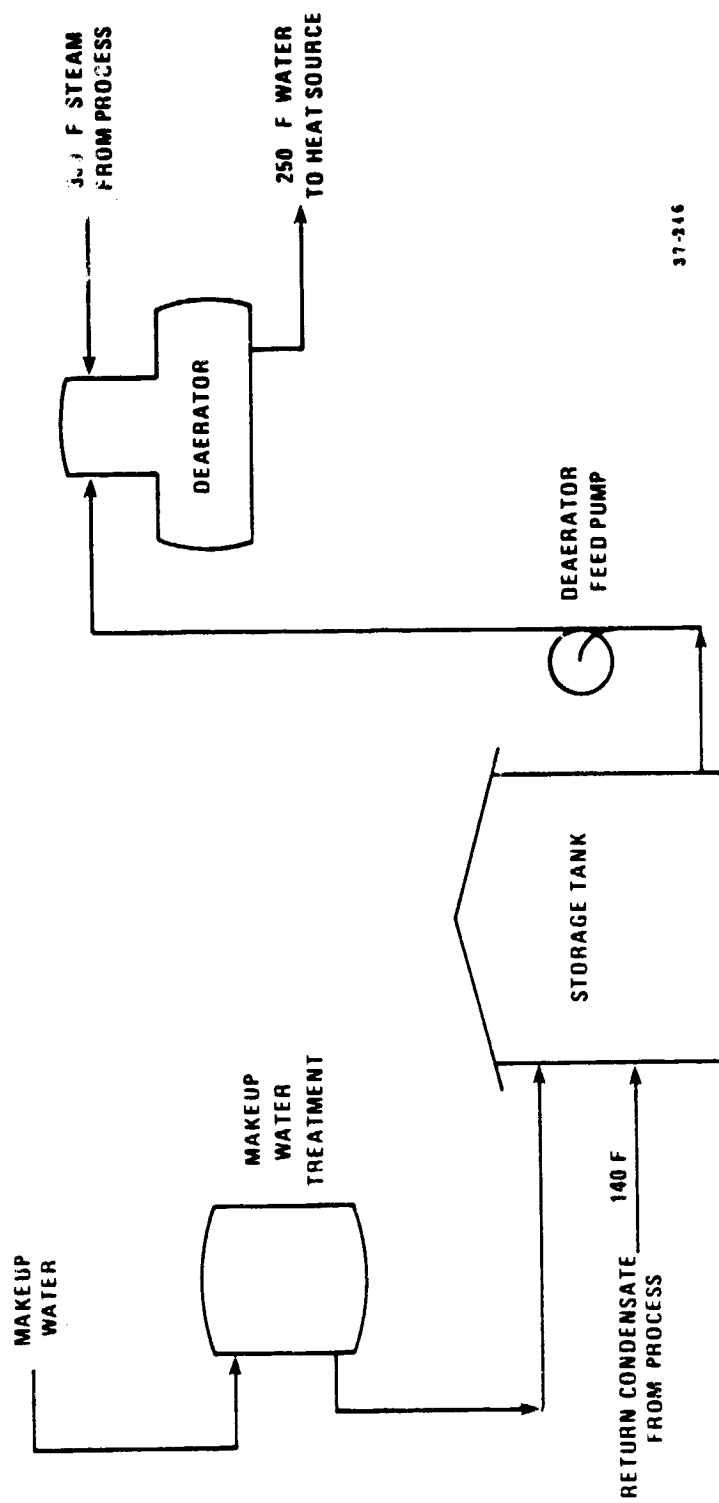


FIGURE IV-70 BOILER FEEDWATER SYSTEM

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COST IN MID-1978 DOLLARS

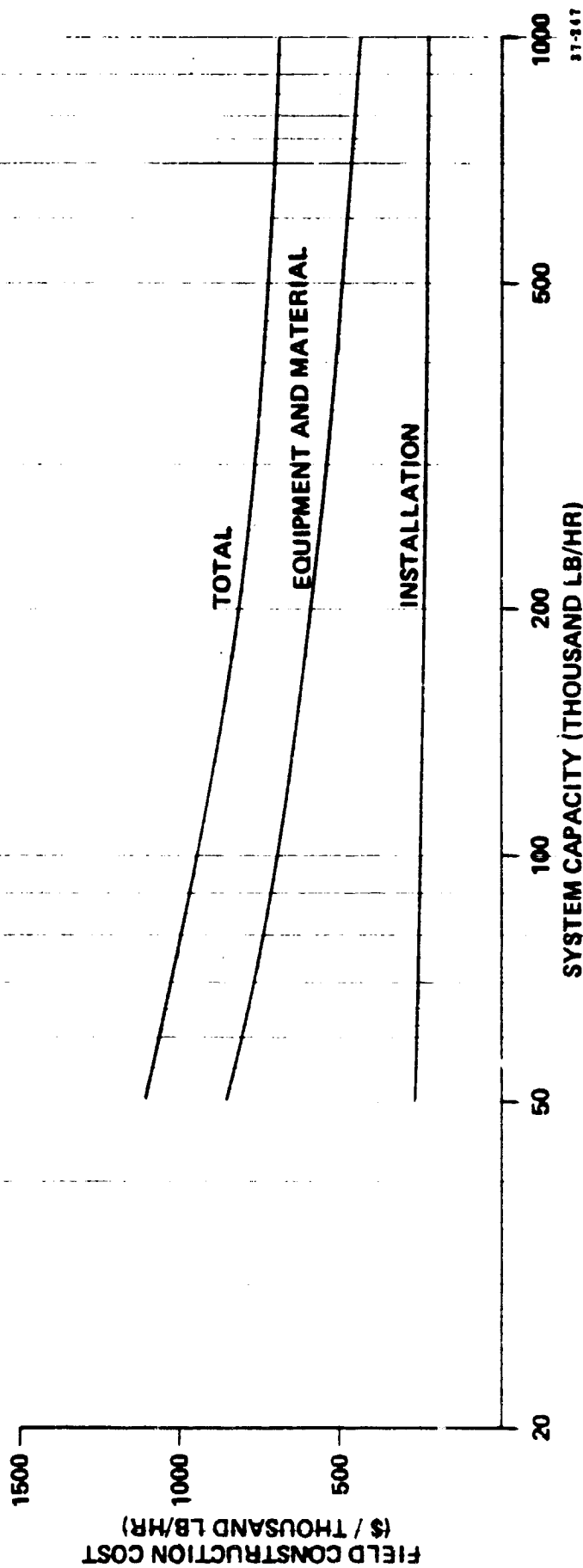


Figure IV-71 VARIATION OF FIELD CONSTRUCTION COST WITH SYSTEM CAPACITY FOR BOILER FEED WATER SYSTEM.

TABLE IV-62
BOILER FEEDWATER SYSTEM
FIELD CONSTRUCTION COST
(500,000 LB/HR FEEDWATER FLOW)

<u>ITEMS</u>	<u>DOLLARS</u>
Equipment	
Deaerator	47,000
Demineralizer	28,000
Tanks	55,000
Pumps	7,000
Civil/Structural	40,000
Piping/Instrumentation	<u>65,000</u>
Total Equipment and Materials	242,000
Direct Installation Labor (@ \$14/4H)	68,000
Indirects (@ 75% of Direct Labor)	<u>51,000</u>
Total Field Construction Cost (Mid-1978 Dollars)	361,000 =====

SYSTEM 10 HEAT REJECTION SYSTEM

The heat rejection system is shown schematically in Figure IV-72. It provides the low temperature heat sink for the energy conversion process and dissipates the reject heat to the atmosphere in an evaporative process. The system includes a wet, mechanical draft cooling tower, circulating water pumps, a makeup water pump, and the system piping. Design and operating characteristics for heat rejection systems dissipating 10 million to 1000 million Btu/hr are as follows.

Characteristics

- Evaporative, mechanical draft cooling tower

<u>Design Conditions</u>	<u>Hot Day</u>	<u>Average Day</u>
Wet Bulb Temperature	77.0F	51.5F
Approach	10.0	23.5
Cold Water Temperature	87.0	75.0
Range	25.0	25.0
Hot Water Temperature	112.0	100.0

- Circulating water pumps
- Makeup water pump.

Number of Units of Major Equipment Items

<u>Item</u>	<u>Heat Rejection Rate Million Btu/hr</u>	<u>Number of Operating Units</u>
Cooling Tower	All Sizes	1
Circulating Water Pumps	All Sizes	2
Makeup Water Pump	All Sizes	1

Utility Requirements

- Electric power is required for the cooling tower fans and the pumps. The power requirement is 3.25 kwe per million Btu/hr of heat rejected
- Makeup water is required to compensate for losses due to drift, evaporation, and blowdown. The makeup water flow rate is 1,350 pounds per million Btu of heat rejected.

Capital Cost

Figure IV-73 shows the field construction cost as a function of rejected heat. The cost breakdown for the design point heat rejection of 100 million Btu/hr is presented in Table IV-63.

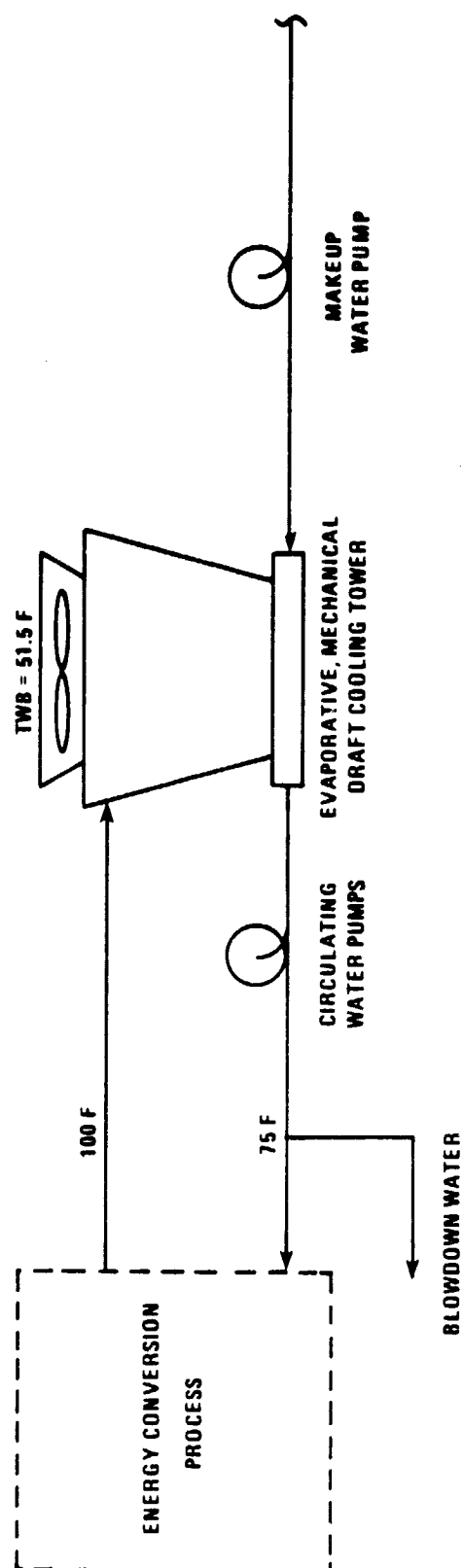


FIGURE IV-72 HEAT REJECTION SYSTEM

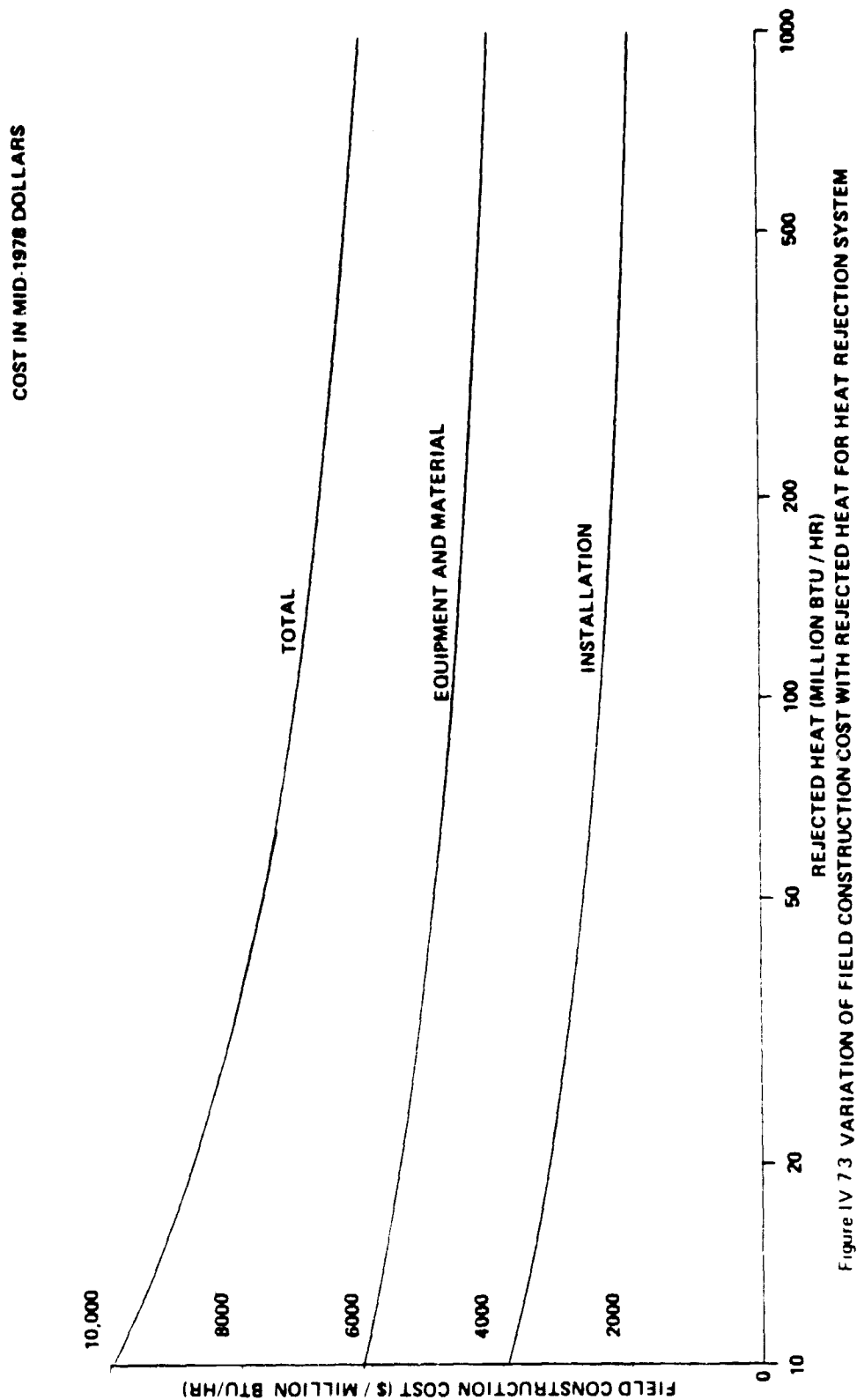


Figure IV 7.3 VARIATION OF FIELD CONSTRUCTION COST WITH REJECTED HEAT FOR HEAT REJECTION SYSTEM

TABLE IV-63
HEAT REJECTION SYSTEM
FIELD CONSTRUCTION COST
(100 MILLION BTU/HR)

<u>ITEMS</u>	<u>DOLLARS</u>
Equipment	
Cooling Towers (Subcontract)	108,000
Pumps	29,000
Civil/Structural	36,000
Piping/Instrumentation	<u>299,000</u>
Total Equipment and Materials	472,000
Direct Installation Labor (@ \$14/MH)	138,000
Indirects (@ 75% of Direct Labor)	<u>104,000</u>
Total Field Construction Cost (Mid-1978 Dollars)	714,000 =====

SYSTEM 11
ELECTRICAL CONDITIONING AND CONTROL SYSTEM

The electrical conditioning and control system provides the auxiliary electric power for the cogeneration facility. The electrical system draws a portion of the electrical energy provided by the plant generator, reduces the voltage from 13.8 kV to 4160 V and to 480 V, and distributes the energy to the balance of plant systems. Figure IV-74 shows a typical auxiliary electrical single line diagram. The following equipment is included in the electrical system:

- 13.8/4.16 kV station service transformer
- 4160/480 V load center transformers
- 4160 V switchgear
- 4160/480 V load centers and 480 V motor control centers
- Interconnecting bus, cable, and conduit
- Central cable spreading room and control room.

Electrical equipment items which can be attributed to specific balance of plant systems, such as motor starters or the cable from the starters to the motors, are not included in the auxiliary electrical system. The plant's main transformer and startup transformer are also excluded.

One station service transformer will decrease the plant generator voltage from 13.8 kV to 4160 V. Electric power, from the 4160 V switchgear, will be supplied to all motors above 200 bhp. The load centers will reduce the voltage from 4160 to 480 to supply power to the motor control centers. All motors below 200 bhp will be supplied power at 480 V from the motor control centers. The percentages of plant auxiliary loads assumed to operate at 480 V is shown in Figure IV-75 as a function of the total auxiliary load.

Capital Cost

Figure IV-76 shows the field construction cost as a function of system rating. The cost breakdown for the design point system rating of 1500 kWe is presented in Table IV-64.

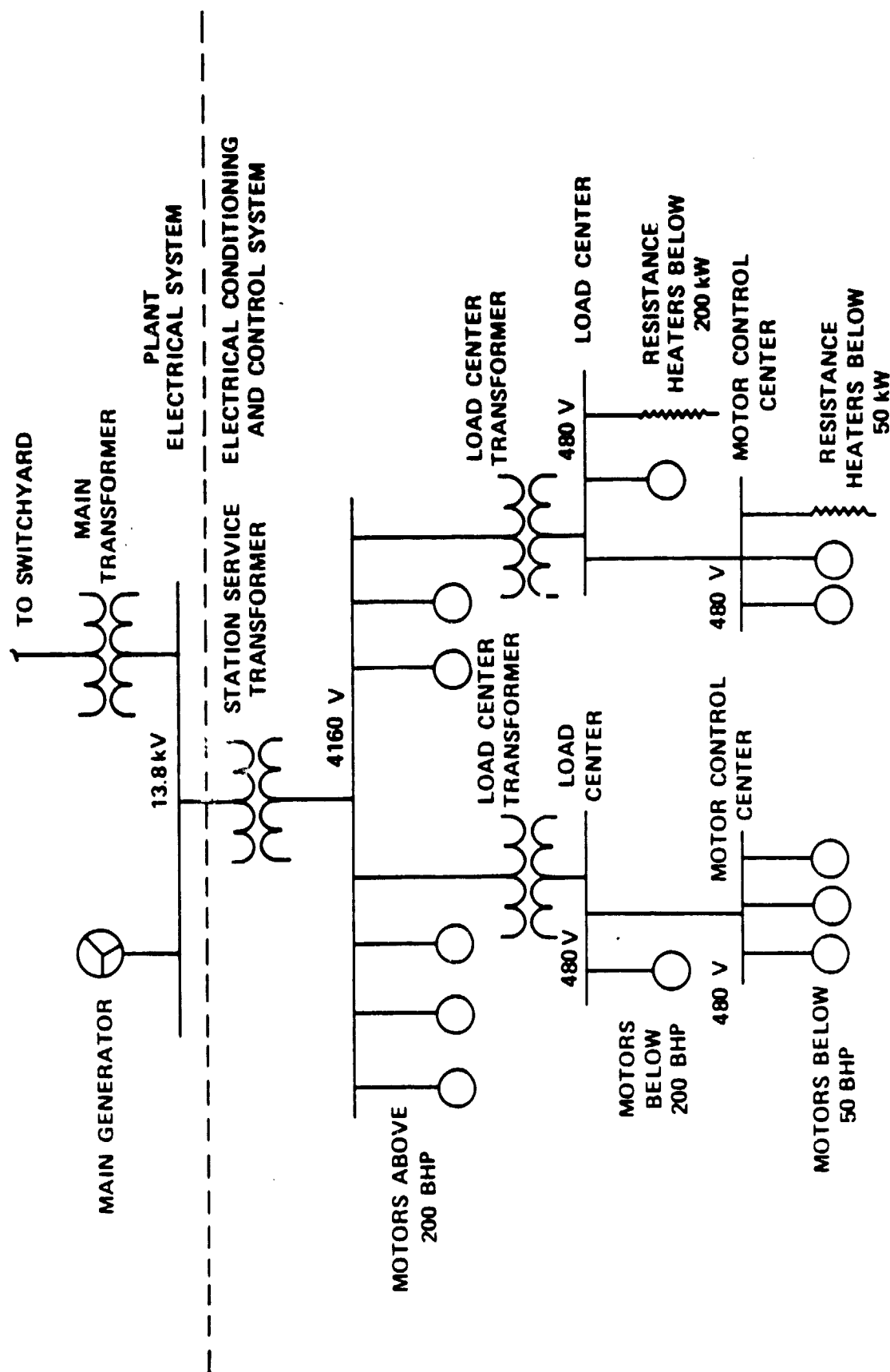


Figure IV-74 ELECTRICAL CONDITIONING AND CONTROL SYSTEM
TYPICAL ELECTRICAL SINGLE LINE DIAGRAM

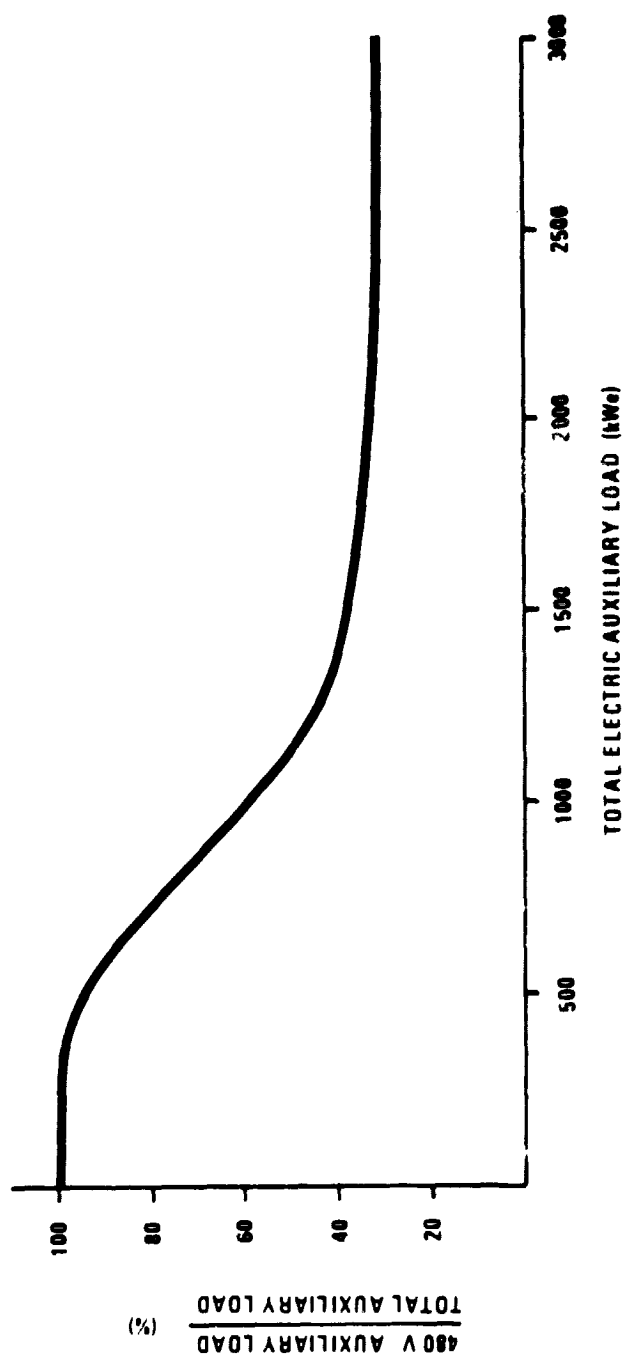
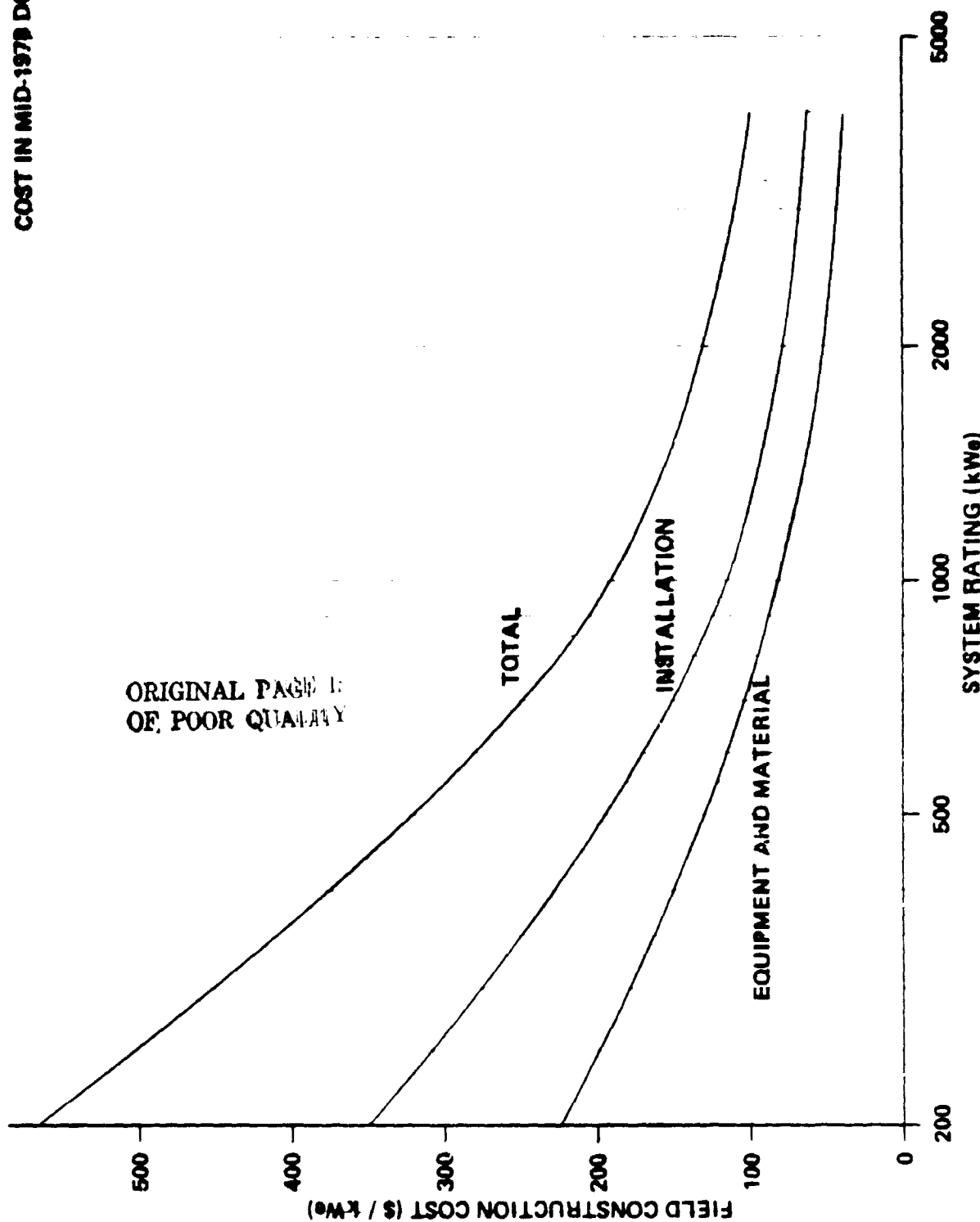


Figure IV-75 ELECTRICAL CONDITIONING AND CONTROL SYSTEM
AUXILIARY LOAD VOLTAGE DISTRIBUTION

COST IN MID-1978 DOLLARS



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Figure IV-76 VARIATION OF FIELD CONSTRUCTION COST WITH SYSTEM RATING FOR ELECTRICAL CONDITIONING AND CONTROL SYSTEM.

TABLE IV-64
ELECTRICAL CONDITIONING AND CONTROL SYSTEM
FIELD CONSTRUCTION COST
(1500 kWe)

<u>ITEMS</u>	<u>DOLLARS</u>
Equipment	
4160 Volt Switchgear	13,000
4160/489 V Transformer	20,000
Control Panels	30,000
Other	32,000
Civil/Structural	-0-
Piping/Instrumentation	<u>-0-</u>
Total Equipment and Materials	95,000
Direct Installation Labor (@ \$14/MH)	74,000
Indirects (@ 75% of Direct Labor)	<u>55,000</u>
Total Field Construction Cost (Mid-1978 Dollars)	224,000 =====

SYSTEM 12
ENERGY CONVERSION SYSTEM BUILDING

The energy conversion system building provides an enclosure for the various energy conversion systems. The building type will vary with size. Small buildings are assumed to be of the pre-engineered metal type while the larger ones will be a metal building, similar in construction to the turbine building of a power plant, with sufficient structure to support an equipment crane.

The field construction cost of System 12, Energy Conversion System Building, is given by the following function.

$$C = KA + 4400T$$

where C = building field cost (dollars)
A = building plan area (sq ft)
K = building cost per sq ft (dollars)

<u>Building Height</u>	<u>K</u>
20 (ft)	50 (Dollars/sq ft)
40	70
60	95
80	125

T = building crane lifting capacity (tons)

SYSTEM 13
SITE PREPARATION AND DEVELOPMENT

Site preparation and development includes those items which are not a part of a particular plant system and are a function of the site area. Included in site preparation and development are:

- Excavation, grading, and landscaping
- Roads, walks, and parking areas
- Site utilities including yard lighting
- Yard fire protection
- Fences and gates.

The field construction costs of System 13, Site Preparation and Development, are estimated at 1 percent of the total cogeneration plant field construction cost.

SYSTEM 14
ENERGY CONVERSION EQUIPMENT INSTALLATION

The energy conversion equipment installation is not a true system but a balance of plant category which includes those capital cost items associated with the equipment which are normally supplied by the architect-engineer. These include the following:

- Foundations and support steel for equipment items
- Field labor for installation and testing of equipment items
- Miscellaneous field purchased materials required for equipment installation.

The energy conversion equipment is assumed to be shop fabricated and require minimal field assembly. Two major categories of equipment are being considered.

- 1) Rotating equipment (e.g. pumps, turbines)
- 2) Erected equipment (e.g. tanks, vessels).

Costs of energy conversion equipment installation, which will be supplied along with the other balance of plant system costs, will be related to the equipment weight and cost.

The field construction costs for installation of the Energy Conversion Equipment, System 14, are estimated for two major categories of equipment as follow:

- Erected equipment (e.g., tanks, vessels) installation costs are estimated at \$850 per ton of equipment weight.
- Rotating equipment (e.g., pumps, turbines) installation costs are shown as a function of equipment shaft horsepower in Figure IV-77.

COST IN MID-1978 DOLLARS

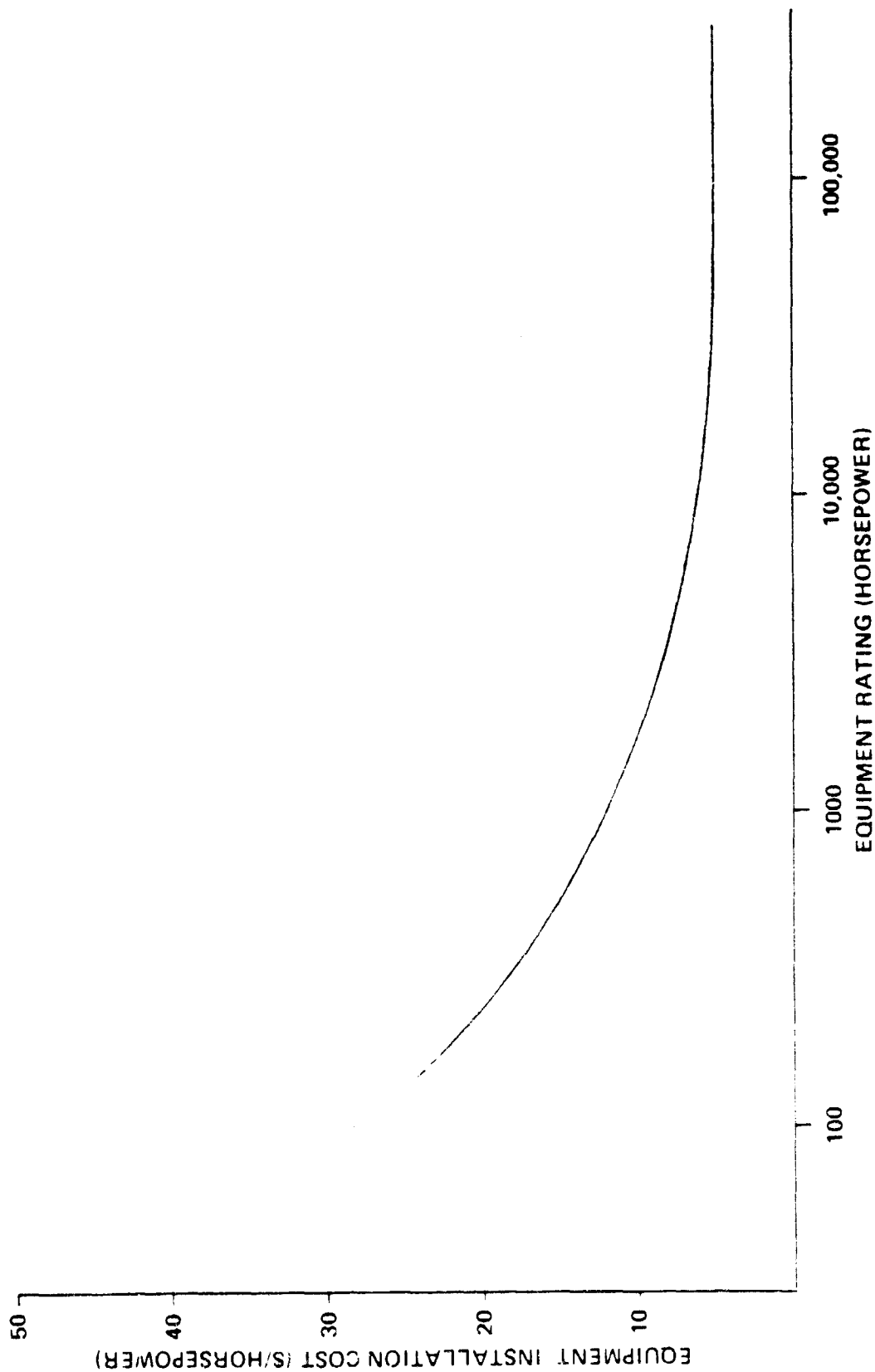


Figure IV 77 VARIATION OF INSTALLATION COST WITH EQUIPMENT RATING FOR ROTATING EQUIPMENT

E. HEAT PUMPS

1.0 INTRODUCTION

Under ideal conditions the output available from an energy conversion system will exactly match the thermal and electric requirements of an industrial process, but this situation is rarely achieved. In some cases conversion system heat is available at temperatures higher than that required by the industrial process and is therefore always thermodynamically useful. Conversely, there are also other conversion system-industrial process configurations where some, if not all, of the recovered heat is not usable because its temperature or quality is below that required. In these situations an industrial heat pump may provide an opportunity to effectively use available low quality heat.

One of the cogeneration strategies involves sizing the energy conversion system such that the power produced meets the process electric requirements and also provides electricity to operate a heat pump. The process thermal needs would be met by heat recovered from the energy conversion system supplemented by heat output from the heat pump. A simple schematic of this system is shown in Figure IV-78. As shown, the heat pump interfaces directly with the cogeneration system utilizing it as the sole source of heat to upgrade process return flows.

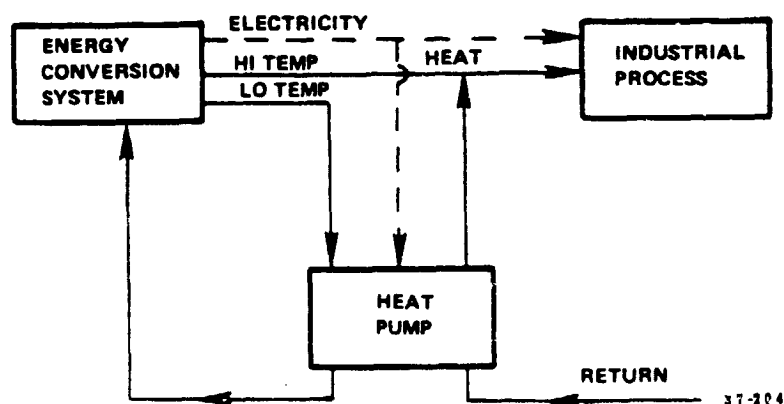


Figure IV-78 Heat Pump Application Schematic

The use of heat pumps to economically promote energy conservation in industrial applications is not new. Typical applications involve the utilization of building or manufacturing process low grade (60°F to 120°F) waste heat sources. Heat is removed from these waste sources by the heat pump and delivered as useful energy at temperatures up to 220°F. At present there has been little incentive to develop equipment capable of higher temperature outputs. With present working fluids, temperature lifts (delivery minus source temperatures) over 80°F require two or more stages of compression, thereby increasing system cost and complexity. In addition, higher stages of compression require increased power input reducing system efficiency or coefficient of performance. As a general rule, present systems are limited to temperature lifts of less than 100°F for economic reasons.

The cogeneration application for heat pumps used in this study is unusual and not now being pursued by industry. In essence, the addition of a heat pump to an energy conversion system provides a mechanism to alter the electric/thermal balance of the system in order to provide a better match to the process requirements. Depending on the system requirements, this can potentially involve a considerable investment in heat pump equipment. An alternative, and possibly more cost effective, approach would involve a redesign of the energy conversion system whereby the system is optimized for higher temperature thermal output at the expense of electric efficiency while eliminating the capital investment in heat pump equipment.

For the purposes of this study, industrial process thermal requirements have been classified into five categories: 140°F hot water, 300°F, 500°F, 700°F steam and hot gases. Heat pump systems investigated were limited to the three steam conditions. Heat pump systems with 140°F water delivery were not considered since most of the energy conversion systems provided waste temperature streams at or above this temperature. Hot gas systems, typically over 1000°F, were considered well beyond the limits of near term future (before the year 2000) heat pumps. The heat pump system conditions are specified in Table IV-65.

TABLE IV-65 HEAT PUMP DESIGN CONDITIONS

<u>Industrial Process</u>		<u>Energy Conversion System</u>
<u>Supply by</u> <u>Heat Pump</u>	<u>Return to</u> <u>Heat Pump</u>	<u>Heat</u> <u>Waste Stream Flow</u>
300°F steam	200°F water	140°F water
500°F steam	200°F water	300°F steam
700°F steam	200°F water	500°F steam

All of the heat pump output requirements are above the present 220°F output capability of commercial industrial heat pumps. Temperature lift requirements are also ambitious, ranging from 160°F to 200°F. Westinghouse Electric Company has reviewed these heat pump requirements and offered the following comments:

300°F Steam: On-going programs indicate that the technology will probably be available by the 1990's. Strong candidate for working fluid will be methanol. CTAS heat source at 140°F (160°F temperature lift) comprises economic competitiveness.

500°F Steam: No known technology programs at these conditions due mainly to market application uncertainties. One possible working fluid would be steam. The 200°F temperature lift requirement felt to preclude economic considerations.

700°F Steam: Technology unlikely before the year 2000.

2.0 HEAT PUMP PERFORMANCE

Heat pump performance is generally measured in terms of a dimensionless parameter called the coefficient of performance or COP. In the heating mode, COP is determined by the ratio of condenser heat rejection divided by compressor input energy. Typical Westinghouse industrial heat pump performance data are shown in Figure IV-79 for both single and two stage compressor configurations.

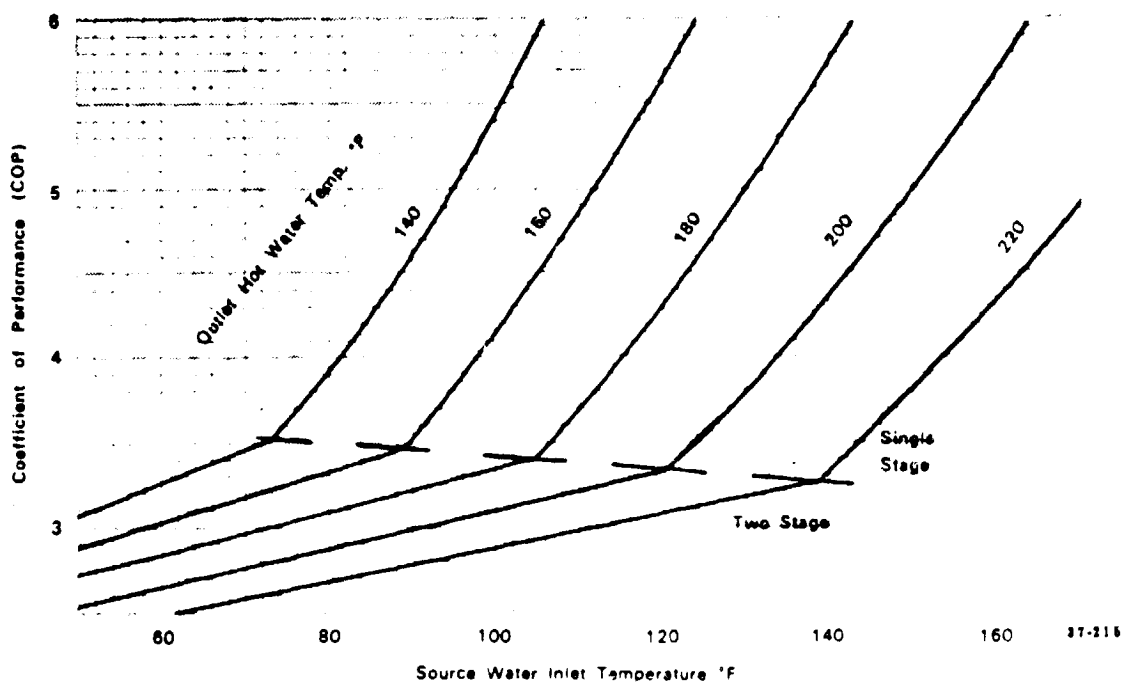


Figure IV-79 Current Industrial Heat Pump Efficiency

In an effort to understand these data to extrapolate to other temperature conditions, the above actual COP's were related to their corresponding carnot or Ideal COP's. The resulting correlation is shown in Figure IV-80. Applying this correlation to the 300°F and 500°F heat pump delivery conditions yields a COP (Ideal) ~4.8 for both with a correlation predicted COP (actual) ~2.5. Since the actual equipment, working fluids, compression stages, etc., would vary at the higher temperature conditions, the use of the above correlation should be utilized only for scoping estimates in lieu of more detailed thermodynamic cycle analyses. However, as a check against the correlation, a number of cycle analyses were performed using methanol and steam as the working fluids at the 300°F and 500°F conditions, respectively. For these cases the agreement between the actual cycle COP's and the corresponding correlating estimates were within 2 to 8% error. As a result of this agreement it was concluded that the use of the correlation would be suitable for the purposes of this study.

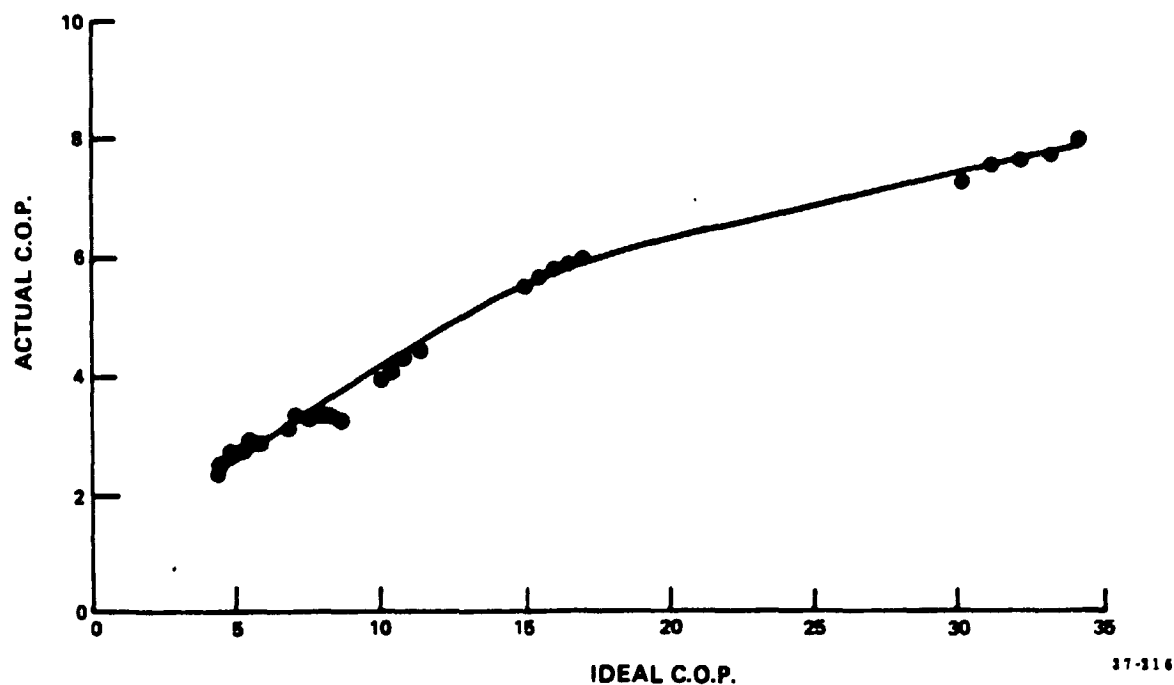


Figure IV-80 Current Industrial Heat Pump Performance

3.0 HEAT PUMP COSTS

Heat pump capital cost estimates were based on data provided by Westinghouse Electric Company. The estimated cost of a complete system was \$370,000 for a methanol cycle unit capable of delivering 18.3 million BTU/hour to a saturated steam sink at 35 psig (281°F) from a saturated steam heat source at 220°F. Costs at other heat output conditions were estimated based on a thermodynamic cycle analysis at the above conditions and specific compressor frame costs versus volumetric flow data. These estimates are shown in Figure IV-81.

The estimated installation cost was equal to the heat pump equipment cost for retrofit applications in existing processes in plants already constructed. These installations typically require additional piping, electrical, foundations, etc. Installation time can vary from three to six months.

Maintenance and overhaul cost can vary between negligible to 25% of the operating costs. If heat source and sink fluid are clean and non-corrosive and the equipment runs above 90% capacity factor with very few starts, maintenance and overhaul cost will be negligible. On the other hand, there may be applications where heat exchangers would have to be cleaned monthly and the units might be started a half dozen times a day which could lead to the need for seal and/or bearing replacement every six months. In this latter case, the maintenance and overhaul costs would approach 25% of the operating costs.

Down time estimates for maintenance and overhaul range from 2 to 3 days for cleaning U-tube boilers or normal compressor seal changes to 1 to 2 weeks for complete overhauls.

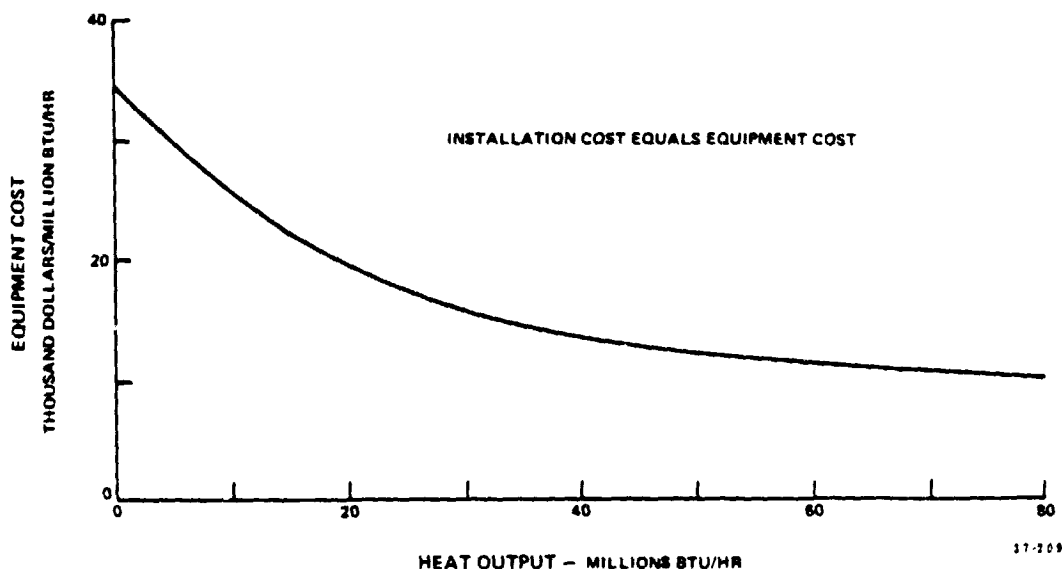


Figure IV-81 Estimated Industrial Heat Pump Equipment Cost

Power Systems Division

FCR-1333

F. CAPITAL COST ESTIMATE REVIEW

1. INTRODUCTION

This section presents the results of a review by Bechtel National Incorporated of the capital cost estimates for representative cogeneration plants which were selected from the more than 3000 cases considered in the study. The capital cost estimates were generated by United Technologies from parametric cost data supplied by Bechtel National for heat sources and balance of plant systems and by other CTAS team members for energy conversion systems. The purpose of the review was to aid in establishing a level of credibility of the CTAS parametric cost analysis.

A two phase approach was taken in reviewing the seventeen cost estimates. First, each item in each estimate was considered subjectively and rated according to the level of confidence of the item's accuracy. Second, based on this preliminary review, specific items or cost categories within each estimate were selected for a more detailed capital cost evaluation.

The general results of the review are as follows:

- Use of Bechtel Parametric Cost Data. The Bechtel parametric cost data was generally used as intended to develop the cost estimates. Only one discrepancy, the cost of the Special Emissions Control in Case 9, was identified which had an impact on the total plant cost of more than five percent.
- Cost Comparison with Other Sources. In the cost categories examined, the costs from the UTC report were generally within the range of data identified from other sources. Only one additional discrepancy was identified, the cost of the Gasifier (ECS) in Case 8, which would have a significant impact on the plant total capital cost.

2. PRELIMINARY REVIEW

2.1 APPROACH

The preliminary review of the estimates was conducted by a panel of cost engineers who are experienced in both conceptual estimates of advanced technology systems and detailed estimates of projects under construction. Two of the four-man panel had contributed to the parametric cost curves which were the basis of the estimates.

In an eight hour review, the panel considered each of the 272 (17 plants x 16 items per plant) items supplied in the UTC capital cost estimates and assigned a confidence factor ranging from zero to five for each item. The confidence factors were defined as follows:

<u>Confidence Factor</u>	<u>Meaning</u>
0	Correct
1	Probably Correct
2	Neutral
3	Suspect
4	Very Suspect
5	Definitely Incorrect

A confidence index was computed for each cost category in each cost estimate as the product of the confidence factor for each item in the cost category and the percent the item's cost contributed to the total plant capital cost. This index was used as one basis for selecting cost categories for further study.

2.2 RESULTS

The confidence indices which resulted from the preliminary analysis are given in Table 2-1. The cases or plants considered, numbered 1 through 20 across the top of the table, are identified in Table 2-2. The cost categories, numbered 1 through 8 down the side of the table, are identified in Table 2-3. Cases 3, 13 and 20 were not included in the review because cost estimates were not available for those cases.

The circled indices of Table 2-1 indicate those cost categories which were selected for further capital cost evaluation. The selection was made on the following basis:

- Items with high confidence indices were selected.
- At least one case of each cost category type was reviewed.

TABLE 2-1
CAPITAL COST CONFIDENCE RATES¹

Cost Category	Cases																			
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1	(55)	18	--	1	18	9	5	8	29	31	17	5	--	15	(15)	2	4	(41)	6	--
2	(87)	(168)	--	0	0	2	0	(188)	(116)	(119)	122	0	--	66	2	0	48	92	(84)	--
3	27	25	--	198	188	134	69	16	--	104	43	124	--	52	--	--	--	71	--	--
5	4	0	--	2	(6)	(11)	0	1	--	0	0	0	--	2	8	0	0	21	7	--
6	0	(2)	--	0	0	0	0	0	0	0	1	0	--	2	0	0	0	1	0	--
7	2	4	--	(31)	30	10	0	0	0	0	0	0	--	(13)	2	0	0	3	2	--
8	52	26	--	104	78	78	78	52	26	26	26	52	--	26	78	52	52	52	78	--

Index Value = (Confidence Factor) x (Percent of Total Plant Capital Cost)

where: Confidence Factor = 0 = Correct
 = 1 = Probably correct
 = 2 = Neutral
 = 3 = Suspect
 = 4 = Very suspect
 = 5 = Definitely wrong

²Circles indicate cases for further study

TABLE 2-2

SELECTED CASES FOR CAPITAL COST ESTIMATE

<u>No.</u>	<u>Energy Conversion System</u>	<u>Fuel</u>
1.	Current Steam Turbine	Coal - FGD
2.	Advanced Steam Turbine	Coal - AFB
3.	Advanced High Speed Diesel	Coal-Derived Distillate
4.	Advanced Low Speed Diesel	Coal-Derived Boiler Fuel
5.	Advanced Low Speed Diesel	Powdered Coal
6.	Advanced Gas Turbine	Petroleum Boiler Fuel
7.	Advanced Gas Turbine	Coal-Derived Boiler Fuel
8.	Advanced Gas Turbine	Gasified Coal
9.	Advanced Gas Turbine	Coal-PFB
10.	Advanced Gas Turbine	Coal-AFB
11.	Advanced Closed Cycle Gas Turbine	Coal-AFB
12.	Advanced Steam Injected Gas Turbine	Coal-Derived Boiler Fuel
13.	Advanced Combined Cycle	Coal-Derived Boiler Fuel
14.	Advanced Combined Cycle	Coal-PFB
15.	Advanced Low-Temperature Fuel Cell	Coal-Derived Distillate
16.	Advanced High-Temperature Fuel Cell	Coal-Derived Distillate
17.	Advanced High - Temperature Fuel Cell	Gasified Coal
18.	Advanced Stirling Engine	Coal-AFB
19.	Advanced Thermionic Converter	Coal-Derived Boiler Fuel
20.	Advanced Organic Rankine Cycle	By-Product Hot Gas

TABLE 2-3
CCST CATEGORIES

1. FUEL/WASTE HANDLING AND STORAGE
 - 1.1 FUEL STORAGE AND RETRIEVAL
 - 1.2 LIMESTONE STORAGE AND RETRIEVAL
 - 1.3 WASTE HANDLING SYSTEMS
 - SUB-TOTAL
2. ECS HEAT SOURCE
 - 2.1 HEAT SOURCE
 - 2.2 SPECIAL EMISSIONS CONTROLS
 - 2.3 FEED WATER SYSTEMS
 - 2.4 GASIFIER (ECS)
 - SUB-TOTAL
3. ENERGY CONVERSION SYSTEM (ECS)
 - 3.1 PRIMARY ENERGY CONVERTER
 - 3.2 PRIMARY GENERATOR/INVERTER
 - 3.3 SECONDARY ENERGY CONVERTER
 - 3.4 SECONDARY GENERATOR
 - 3.5 BOTTOMING CYCLE VAPOR GENERATOR
 - 3.6 HEAT RECOVERY EQUIPMENT
 - 3.7 CONDENSERS
 - 3.8 HEAT PUMP
 - SUB-TOTAL
4. THERMAL STORAGE
5. SUPPLEMENTARY HEAT (FURNACE, BOILER)
6. HEAT REJECTION
7. OTHER BALANCE OF PLANT ITEMS
 - 7.1 SITE PREPARATION
 - 7.2 STRUCTURES
 - 7.3 ELECTRICAL CONDITIONING & CONTROL
 - SUB-TOTAL
8. INDIRECT COSTS
 - 8.1 CONTINGENCY
 - 8.2 ENGINEERING AND FEES
 - SUB-TOTAL

- The selection was made to allow review of as many different kinds of systems within a cost category type as possible.
- Cost Category 3, Energy Conversion Systems, was excluded from further review since Bechtel's experience with many of these systems is relatively limited compared to that of other CTAS team members.
- Cost Category 8, Indirect Costs, was excluded from selection and treated on a general basis.

3. CAPITAL COST EVALUATION

The capital cost review of selected cost categories, as indicated by Table 2-1, was carried out by comparing the cost estimate with one or more of the following:

- Parametric cost curves (PCC) developed previously by Bechtel during the course of earlier CTAS work
- Specific order of magnitude cost estimates based on the data utilized for developing the PCC
- Data published in the technical literature for intermediate and advanced technology equipment
- Previous Bechtel estimates for similar equipment.

The following sections identify the case and cost category under consideration, compare the costs taken from the UTC cost report with costs read from the Bechtel PCC and give the results and basis of further cost review.

In cases where the equipment capacity required by the case was outside the range of design capacity used for developing the PCC, the curve was extrapolated. In all such cases the required capacity was considered to fall within a range of reasonable extrapolation.

3.1 COST CATEGORY SELECTION 1

3.1.1 Background

Case No. 1: Current Steam Turbine

Cost Category No. 1: Fuel/Waste Handling and Storage

The following shows the capital costs based on the UTC report and Bechtel PCC.

<u>Item</u>	<u>Capital Cost in Millions</u>	
	<u>UTC Report</u>	<u>Bechtel PCC</u>
1.1 Fuel Storage & Retrieval	9.4	5.1*
1.2 Limestone Storage & Retrieval	1.8	1.4
1.3 Waste Handling System	0.8	1.0*
SUBTOTAL	12.0	7.5

*Extrapolated

3.1.2 Comment

Item 1.1: Review of the previous Bechtel estimate to develop the PCC and a comparison with another Bechtel study indicate that a

capital cost in the range of 5 to 6 million dollars is reasonable for a fuel storage and retrieval system of this capacity.

Item 1.2: Review of previous work to develop the PCC, indicates that the maximum cost of a limestone storage and retrieval system of this capacity is approximately 1.7 million dollars.

Item 1.3: Review of a Bechtel cost estimate for a similar system, indicates that the cost of the handling system of this capacity falls within the limits of 1.0 to 1.3 million dollars.

3.2 COST CATEGORY SELECTION 2

3.2.1 Background

Case No. 15: Advanced Low Temperature Fuel Cell

Cost Category No. 1: Fuel/Waste Handling and Storage

The following shows the capital costs based on the UTC report and Bechtel PCC.

<u>Item</u>	<u>Capital Cost in Millions</u>	
	<u>UTC Report</u>	<u>Bechtel PCC</u>
1.1 Fuel Storage & Retrieval	0.16	0.11
1.2 Limestone Storage & Retrieval	0	0
1.3 Waste Handling System	0	0
SUBTOTAL	0.16	0.11

3.2.2 Comments

Item 1.1: Based on an order of magnitude estimate developed specifically for this facility, the cost is estimated to be approximately 0.1 million dollars.

3.3 COST CATEGORY SELECTION 3

3.3.1 Background

Case No. 18: Advanced Stirling Engine

Cost Category No. 1: Fuel/Waste Handling and Storage

The following shows the capital costs based on the UTC report and Bechtel PCC.

<u>Item</u>	Capital Cost in Millions	
	<u>UTC Report</u>	<u>Bechtel PCC</u>
1.1 Fuel Storage & Retrieval	9.5	5.1*
1.2 Limestone Storage & Retrieval	2.5	3.4*
1.3 Waste Handling System	0.5	1.0*
SUBTOTAL	12.5	9.5

*Extrapolated

3.3.2 Comment

Review of other Bechtel cost estimates applicable to similar systems substantiates the costs reflected by the Bechtel PCC.

3.4 COST CATEGORY SELECTION 4

3.4.1 Background

Case No. 1: Current Steam Turbine

Cost Category No. 2: ECS Heat Source

The following shows the capital costs based on the UTC report and Bechtel PCC.

<u>Item</u>	Capital Cost in Millions	
	<u>UTC Report</u>	<u>Bechtel PCC</u>
2.1 Heat Source	28.5	30.5
2.2 Special Emissions Controls	24.1	17.3
2.3 Feed Water Systems	1.4	1.1*
2.4 Gasifier (ECS)	0	0
SUBTOTAL	54.0	48.9

*Extrapolated

3.4.2 Comment

Item 2.1: Review of previous Bechtel work for developing the PCC and the published data (Ref. 3-1) for a similar system indicates that the cost of two pulverized coal fired boilers of the required capacity is within the range of 25 to 33 million dollars.

Item 2.2: Review of a recent Bechtel study and the published data (Ref. 3-2) for a similar system indicate that the cost of two sulfur dioxide scrubber systems falls in the range of 20 to 26 million dollars.

3.5 COST CATEGORY SELECTION 5

3.5.1 Background

Case No. 2: Advanced Steam Turbine

Cost Category No. 2: ECS Heat Source

The following shows the capital costs based on the UTC report and Bechtel PCC.

<u>Item</u>	Capital Cost in Millions	
	<u>UTC Report</u>	<u>Bechtel PCC</u>
2.1 Heat Source	34.1	32.5
2.2 Special Emissions Controls	0	0
2.3 Feed Water Systems	1.3	1.3
2.4 Gasifier (ECS)	0	0
SUBTOTAL	35.4	33.8

3.5.2 Comment

Item 2.1: Based on published data (Ref. 3-1, 3-3 and 3-4) applicable for similar systems, it is estimated that the cost of three coal fired atmospheric fluidized bed steam generators of this capacity is in the range of 30 to 40 million dollars.

3.6 COST CATEGORY SELECTION 6

3.6.1 Background

Case No. 8: Gas Turbine

Cost Category No. 2: ECS Heat Source

The following shows the capital costs based on the UTC report and Bechtel PCC.

<u>Item</u>	Capital Cost in Millions	
	<u>UTC Report</u>	<u>Bechtel PCC</u>
2.1 Heat Source	0	0
2.2 Special Emissions Controls	0	0
2.3 Feed Water Systems	0.11	0.46
2.4 Gasifier (ECS)	19.9	NA
SUBTOTAL	20.0	NA

3.6.2 Comment

Item 2.4: Based on several cost estimates developed by Bechtel during previous engineering studies of oxygen blown entrained or fluidized bed systems, it is estimated that the cost of this system falls in the range of 30 to 42 million dollars.

3.7 COST CATEGORY SELECTION 7

3.7.1 Background

Case No. 9: Gas Turbine

Cost Category No. 2: ECS Heat Source

The following shows the capital costs based on the UTC report and Bechtel PCC.

<u>Item</u>	Capital Cost in Millions	
	<u>UTC Report</u>	<u>Bechtel PCC</u>
2.1 Heat Source	112.6	115.2
2.2 Special Emissions Controls	0.03	10.7
2.3 Feed Water Systems	0.65	0
2.4 Gasifier (ECS)	0	0
SUBTOTAL	113.3	149.0

3.7.2 Comments

Item 2.1: Based on a review of published data (Ref 3-5 and 3-6), it is estimated that the cost of a pressurized fluidized bed system of this capacity is approximately 110 million dollars.

3.8 COST CATEGORY SELECTION 8

3.8.1 Background

Case No. 10: Gas Turbine

Cost Category No. 2: ECS Heat Source

The following shows the capital costs based on the UTC report and Bechtel PCC.

<u>Item</u>	Capital Cost in Millions	
	<u>UTC Report</u>	<u>Bechtel PCC</u>
2.1 Heat Source	51.8	56.4
2.2 Special Emissions Controls	0	0
2.3 Feed Water System	0.2	1.3
2.4 Gasifier (ECS)	0	0
SUBTOTAL	52.0	57.7

3.8.2 Comment

Item 2.1: Review of published data (Ref. 3-4) indicates that the cost of two coal fired atmospheric fluidized bed hot gas generator systems is approximately 50 million dollars.

Item 2.3: Review of data previously used for developing the PCC indicates that the cost of feedwater system of this capacity is approximately 1.3 million dollars.

3.9 COST CATEGORY SELECTION 9

3.9.1 Background

Case No. 17: High Temperature Fuel Cell

Cost Category No. 2: ECS Heat Source

The following shows the capital costs based on the UTC report and Bechtel PCC.

<u>Item</u>	<u>Capital Cost in Millions</u>	
	<u>UTC Report</u>	<u>Bechtel PCC</u>
2.1 Heat Source	0	0
2.2 Special Emissions Controls	0	0
2.3 Feed Water Systems	0	0
2.4 Gasifier (ECS)	73.7	NA
SUBTOTAL	73.7	NA

3.9.2 Comment

Item 2.4: Based on review of several Bechtel studies, the cost of a gasifier of this capacity is in the range of 55 to 75 million dollars.

3.10 COST CATEGORY SELECTION 10

3.10.1 Background

Case No. 19: Advanced Thermionic Converter

Cost Category No. 2: ECS Heat Source

The following shows the capital costs based on the UTC report and Bechtel PCC.

<u>Item</u>	<u>Capital Cost in Millions</u>	
	<u>UTC Report</u>	<u>Bechtel PCC</u>
2.1 Heat Source	29.8	27.0
2.2 Special Emissions Controls	0	0
2.3 Feed Water Systems	0.6	1.2
2.4 Gasifier (ECS)	0	0
SUBTOTAL	30.4	28.2

3.10.2 Comment

Item 2.1: Review of published data (Ref. 3-7) indicates that the cost of two THX furnace systems of this capacity is approximately 30 million dollars.

Item 2.3: Review of data used for developing the PCC indicates that the cost of a feedwater system of this capacity is approximately 1.2 million dollars.

3.11 COST CATEGORY SELECTION 11

3.11.1 Background

Case No. 5: Advanced Low Speed Diesel

Cost Category No. 5: Supplementary Heat

The following shows the costs based on the UTC report and Bechtel PCC.

<u>Item</u>	Capital Cost in Millions	
	<u>UTC Report</u>	<u>Bechtel PCC</u>
5 Supplementary Heat (Furnace, Boiler)	1.76	0.24*

*Residual oil fired boiler of similar capacity.

3.11.2 Comment

Based on previous Bechtel work used for developing the PCC for a residual oil fired boiler and other Bechtel studies, it is estimated that the cost of a supplementary boiler of this capacity, suitable for firing residual oil, is in the range of 0.23 to 0.30 million dollars. The cost of a dual fuel fired boiler, capable of firing coal and oil, is approximately 0.9 million dollars. The higher number is more appropriate in this case which is based on firing black liquor and residual oil.

3.12 COST CATEGORY SELECTION 12

3.12.1 Background

Case No. 6: Advanced Gas Turbine

Cost Category No. 5: Supplementary Heat

The following shows the costs based on the UTC report and Bechtel PCC.

<u>Item</u>	Capital Cost in Millions	
	<u>UTC Report</u>	<u>Bechtel PCC</u>
5 Supplementary Heat (Furnace, Boiler)	3.3	5.1*

*Residual oil fired boiler of required capacity.

3.12.2 Comment

Based on previous Bechtel work used for developing the PCC for a residual oil fired boiler and other Bechtel studies, it is estimated that the cost of two residual oil fired supplementary boilers of this capacity is in the range of 4.5 to 5.5 million dollars. The cost of two dual fuel fired boilers is approximately 22 million dollars. The higher cost is more appropriate for this case which is based on firing black liquor and residual oil.

3.13 COST CATEGORY SELECTION 13

3.13.1 Background

Case No. 2: Advanced Steam Turbine

Cost Category No. 6: Heat Rejection

The following shows the costs based on the UTC report and Bechtel PCC.

<u>Item</u>	Capital Cost in Millions	
	<u>UTC Report</u>	<u>Bechtel PCC</u>
6 Heat Rejection	0.6	0.7

3.13.2 Comment

Review of previous Bechtel work for developing the PCC and a specific cost estimate for this plant with more accurate quantification of major circulation water piping, indicate that cost of the system of this capacity is approximately 0.7 million dollars.

3.14 COST CATEGORY SELECTION 14

3.14.1 Background

Case No. 14: Combined Cycle

Cost Category No. 7: Other BOP Items

The following shows the costs based on the UTC report and Bechtel PCC.

<u>Item</u>	<u>Capital Cost in Millions</u>	
	<u>UTC Report</u>	<u>Bechtel PCC</u>
7.1 Site Preparation	0.78	NA
7.2 Structures	3.45	NA
7.3 Electrical Conditioning	<u>0.04</u>	<u>0.28</u>
	4.27	NA

3.14.2 Comments

Item 7.1: The basis for the development of the capital cost for site preparation is estimated as 1% of field construction cost (Total Capital Cost minus Engineering, Fees, and Contingency) and hence for this case $1\% \times (106.5 - 27.6) = 0.78$ million dollars. Based on Bechtel historical data, the assumption of 1% of field construction cost as the cost for site preparation and development is considered valid for a project of this magnitude.

Item 7.2: Based on Bechtel historical data, the cost of structures for the turbine buildings associated with a project of this magnitude is estimated to fall in the range of 0.9 to 1.3 million dollars.

Item 7.3: Based on data used for developing the PCC, it is estimated that the cost of electrical conditioning and control system for a project of this size is approximately 0.28 million dollars.

4. REVIEW OF COST CODE NO. 8, INDIRECT COSTS

4.1 Background

Cost Category 8, Indirect Costs, in the UTC report consists of contingency and engineering and fees. These costs were estimated as a percentage of the total cost of equipment, materials and labor (direct field cost) as follows:

<u>Item</u>	<u>% of Direct Field Cost</u>
8.1 Contingency	20
8.2 Engineering and Fees	15

4.2 Comments

Item 8.1: The contingency allowance included in the cost estimate for well defined projects provides for uncertainties in estimate and schedule detail (quantities, installation manhours, equipment cost, and project duration). The estimated total project cost, including the contingency allowance, reflects the most likely construction cost (it is expected that the probability of overrun equals that of underrun). This contingency allowance does not provide for changes in project scope, design criteria, unlikely events, commercial changes, or schedule slippages outside the control of the Architect-Engineer.

For well defined projects the contingency allowance may be derived from treating the detailed estimate as a sum of partially correlated random variables and by using statistical techniques. However, at the conceptual design stage, contingency must be estimated based on that of other well-defined projects of similar scope. The contingency for steam turbine power plant projects in Bechtel historical records is approximately 15 to 20% of direct field costs. On this basis, the 20% contingency included in the UTC report appears appropriate.

Two caveats should be noted in applying this contingency. First, the contingency is appropriate for well-defined commercial technologies and does not reflect any uncertainties associated with the development of these advanced technology systems. Second, many of these cogeneration plants differ substantially from steam turbine power plants. Differing characteristics which a more detailed study might show to have an effect on contingency include plant size, length of construction period, and fraction of the total plant cost made up of supplier engineered and shop fabricated components.

Item 8.2: Based on Bechtel historical data, it is estimated that the cost of Engineering and Fees is approximately 15% of the total construction cost. The 15%, which is typical for power plants, can generally be broken down into the following:

- 8% to cover home office engineering
- 4% to cover home office support
- 3% to cover all fees

The Engineering and Fees cost can be reduced somewhat by decreasing the total home office engineering when a project has major systems which are pre-engineered by the supplier. Based on Bechtel historical records, it is estimated that the Engineering and Fees cost varies from 15% for projects with no pre-engineered systems, to 10% for projects which are nearly 100% pre-engineered systems. The Engineering and Fees for the seventeen cases selected in the UTC report have been calculated based on applying 10% to the pre-engineered systems and 15% to the non pre-engineered systems. The resulting average engineering and fee is as follows:

<u>UTC Case Numbers</u>	<u>Engineering and Fee as Percent of Field Construction Cost</u>
1 and 2	15
8, 10 and 11	14
14, 17 and 18	13
9 and 19	12
6 and 12	11
4, 5, 7, 15 and 16	10

5. GENERAL COMMENTS

The following are general comments based on the review of the capital cost estimates for seventeen cogeneration plants.

- Use of Bechtel Parametric Cost Data. The Bechtel parametric cost data was generally used as intended to develop the cost estimates. Only one discrepancy, the cost of the special emissions control in Case 9, was identified which had an impact on the total plant cost of more than five percent.
- Cost Category 3, Energy Conversion Systems. The energy conversion systems were considered in the preliminary review only. The comments were as follows:
 - Steam Turbines, Cases 1 and 2: The costs of \$116/kWe and \$133/kW are consistent with data from previous Bechtel estimates.
 - Gas Turbines, Cases 6 through 10: The UTC costs ranging from \$107/kWe to \$143/kWe are consistent with Bechtel data for large gas turbines but seem somewhat low for smaller units.
 - Diesels, Cases 4 and 5: The costs of \$440/kWe appears to be in the right range. Based on Bechtel data, smaller high speed units cost \$300 to \$400/kWe.
 - Stirling Engine, Case 18: Assuming a Stirling Engine has a cost similar to other reciprocating engines such as diesels, a cost of \$153/kWe seems low.
- Cost Comparison with Other Sources. In the cost categories examined, the costs from the UTC report were generally within the range of data identified from other sources. Only one discrepancy was identified in addition to that mentioned above; the cost of the Gasifier (ECS) in Case 8, which would have a significant impact on the plant total capital cost.

6. PLANT LAYOUT

In addition to the review of the capital cost estimates of the selected cases, Bechtel National, Incorporated, reviewed the design of each case and prepared rough, conceptual plant layout sketches which are included in Figures IV-82 through IV-100.

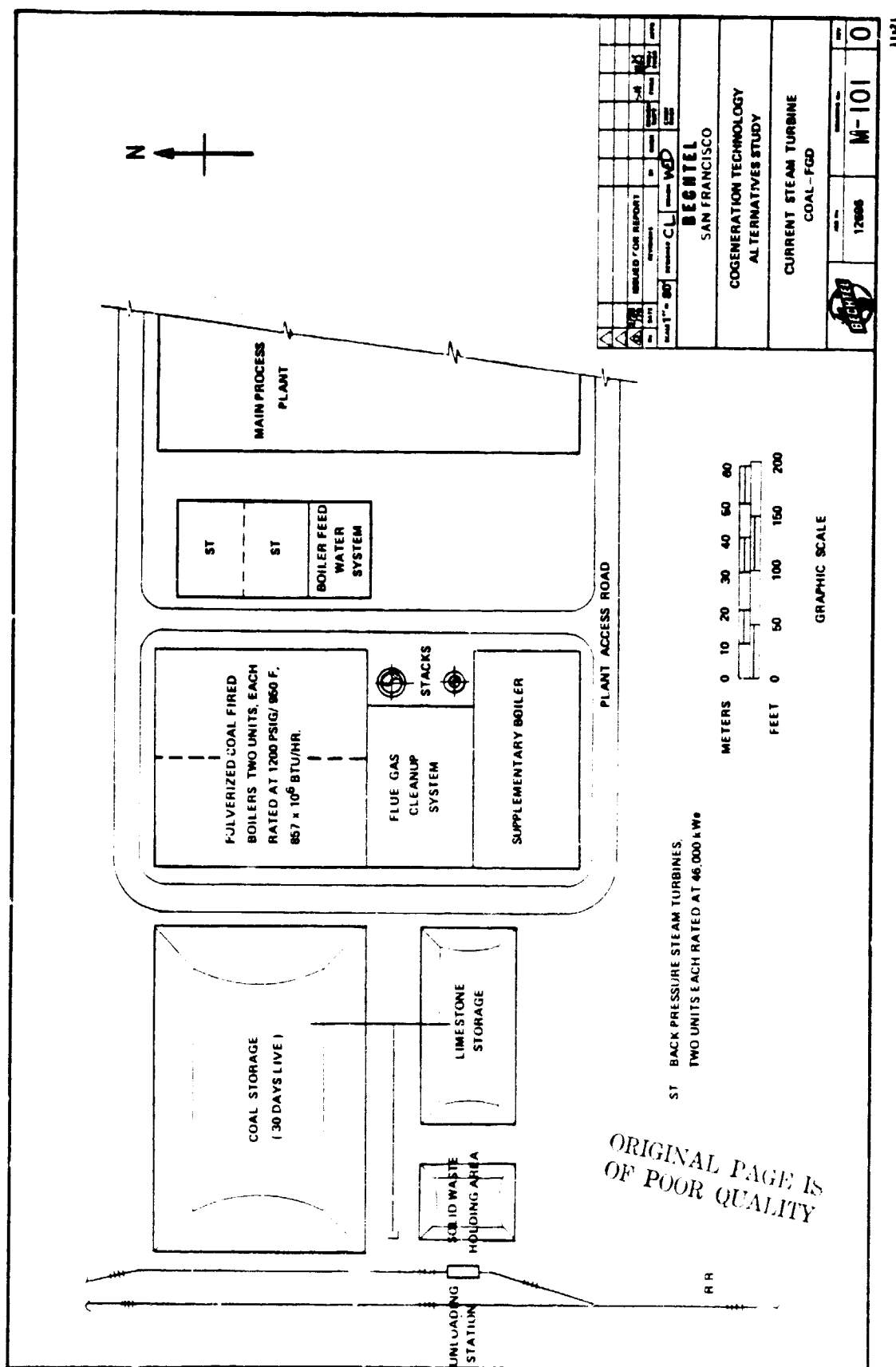


Figure IV-82

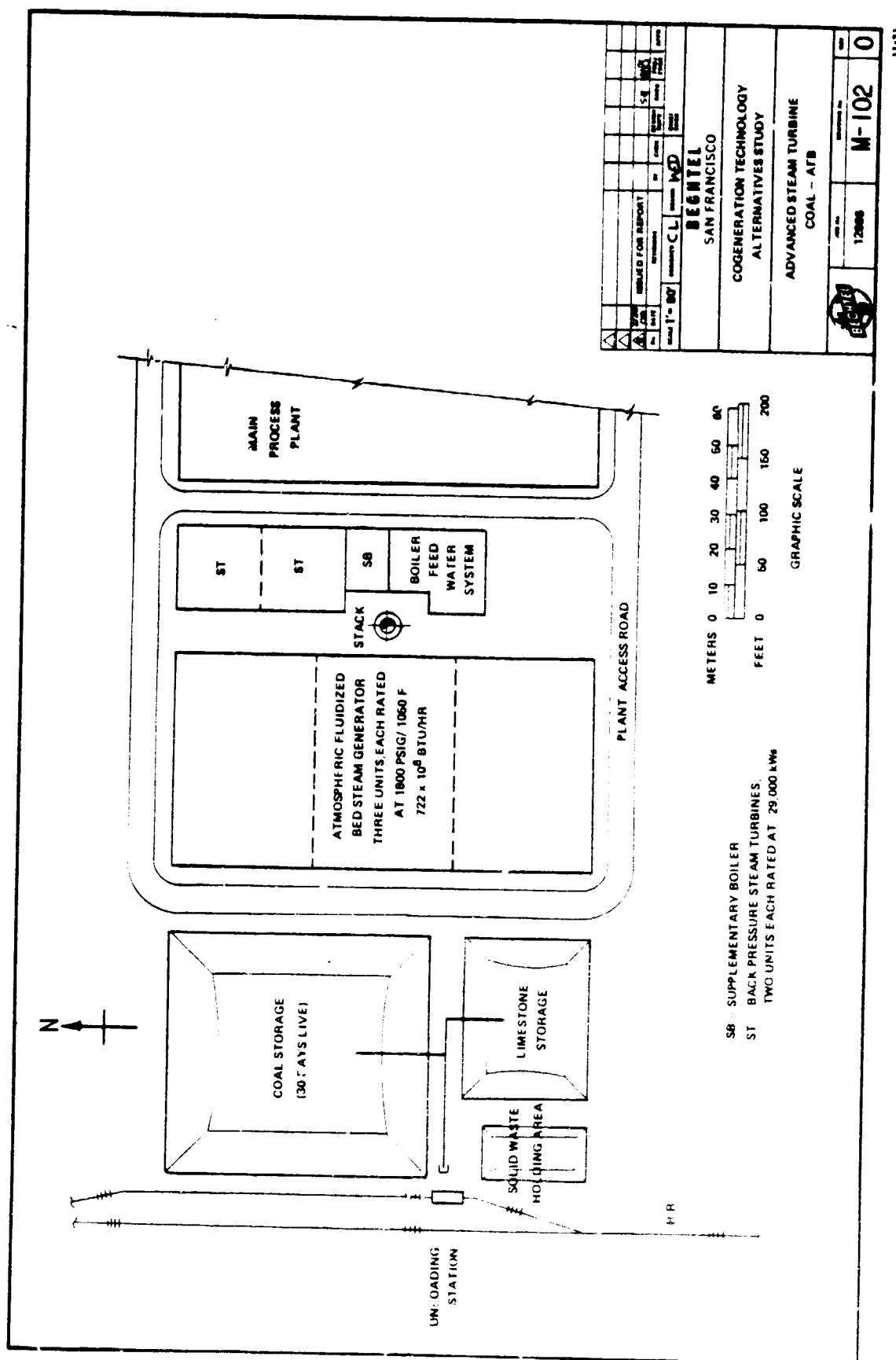


Figure IV-83

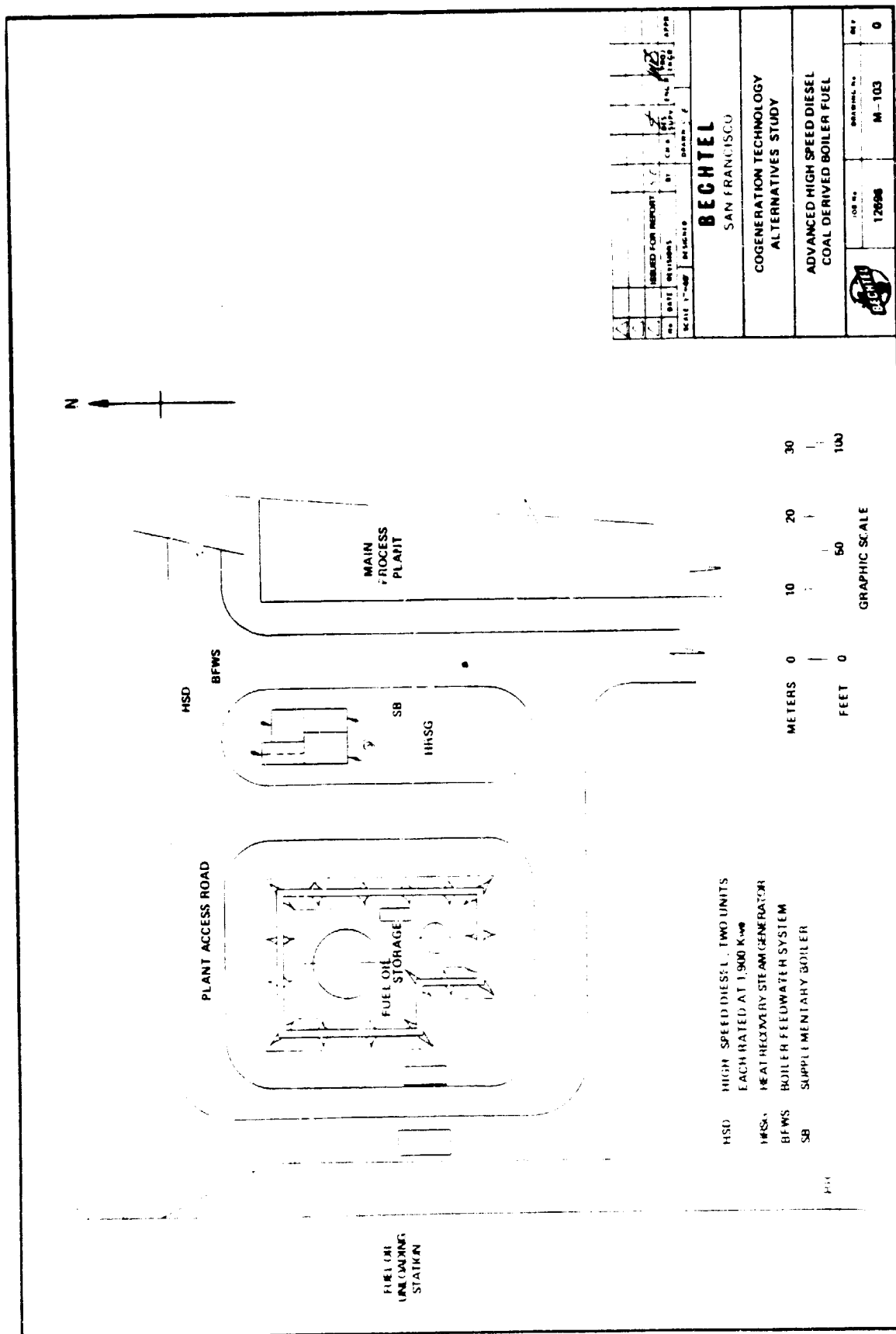


Figure IV-84

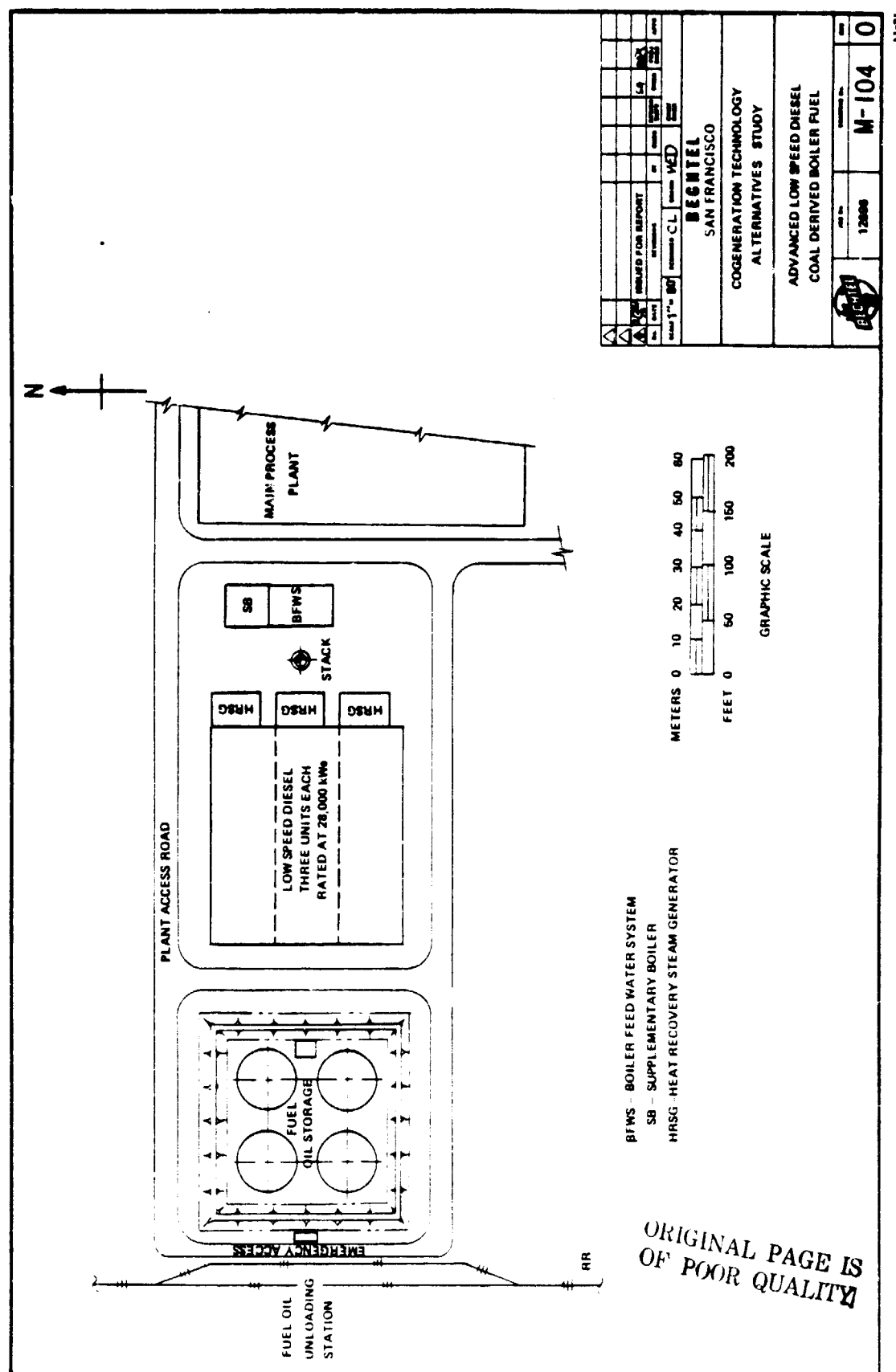


Figure IV-85

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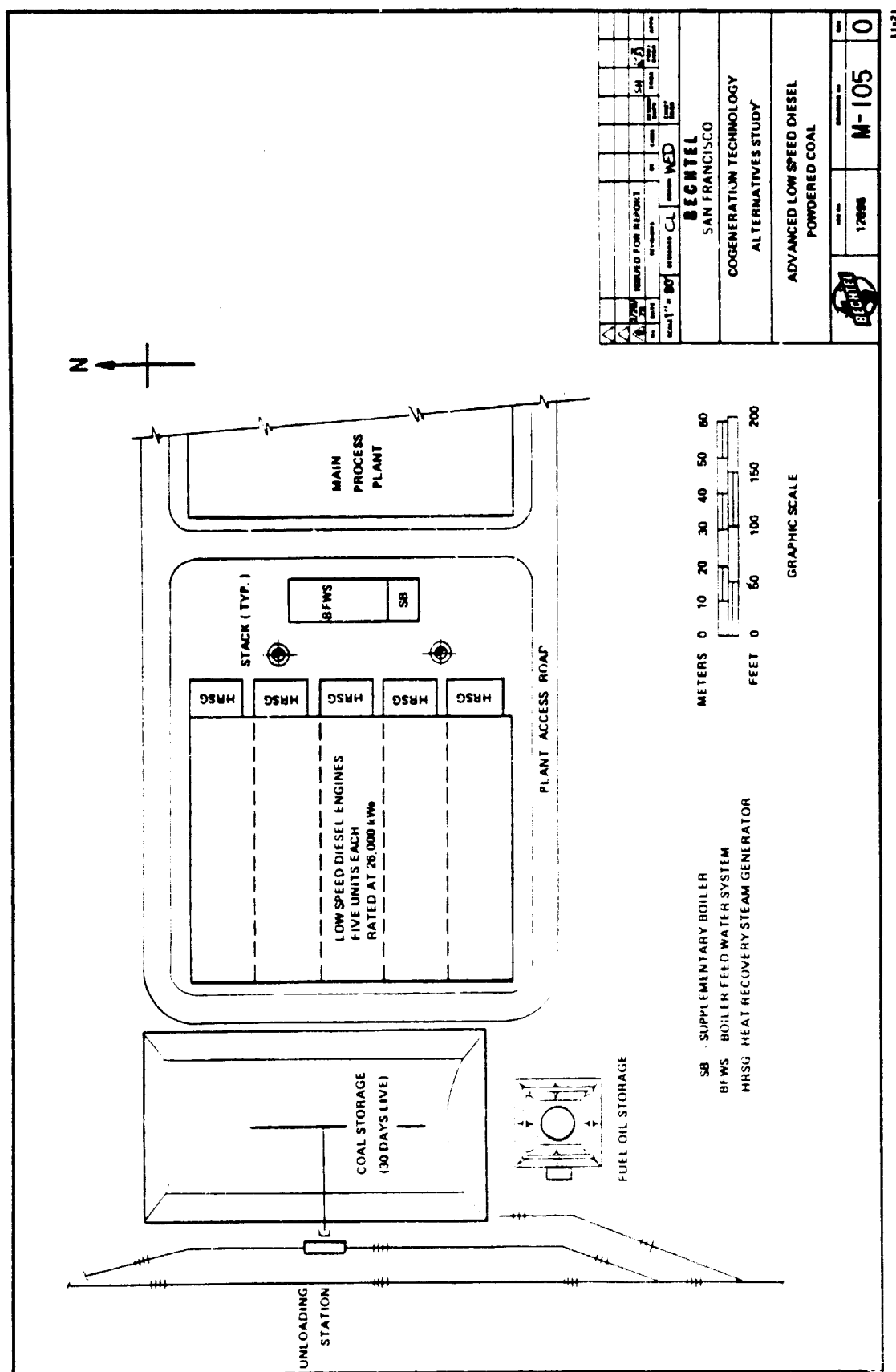


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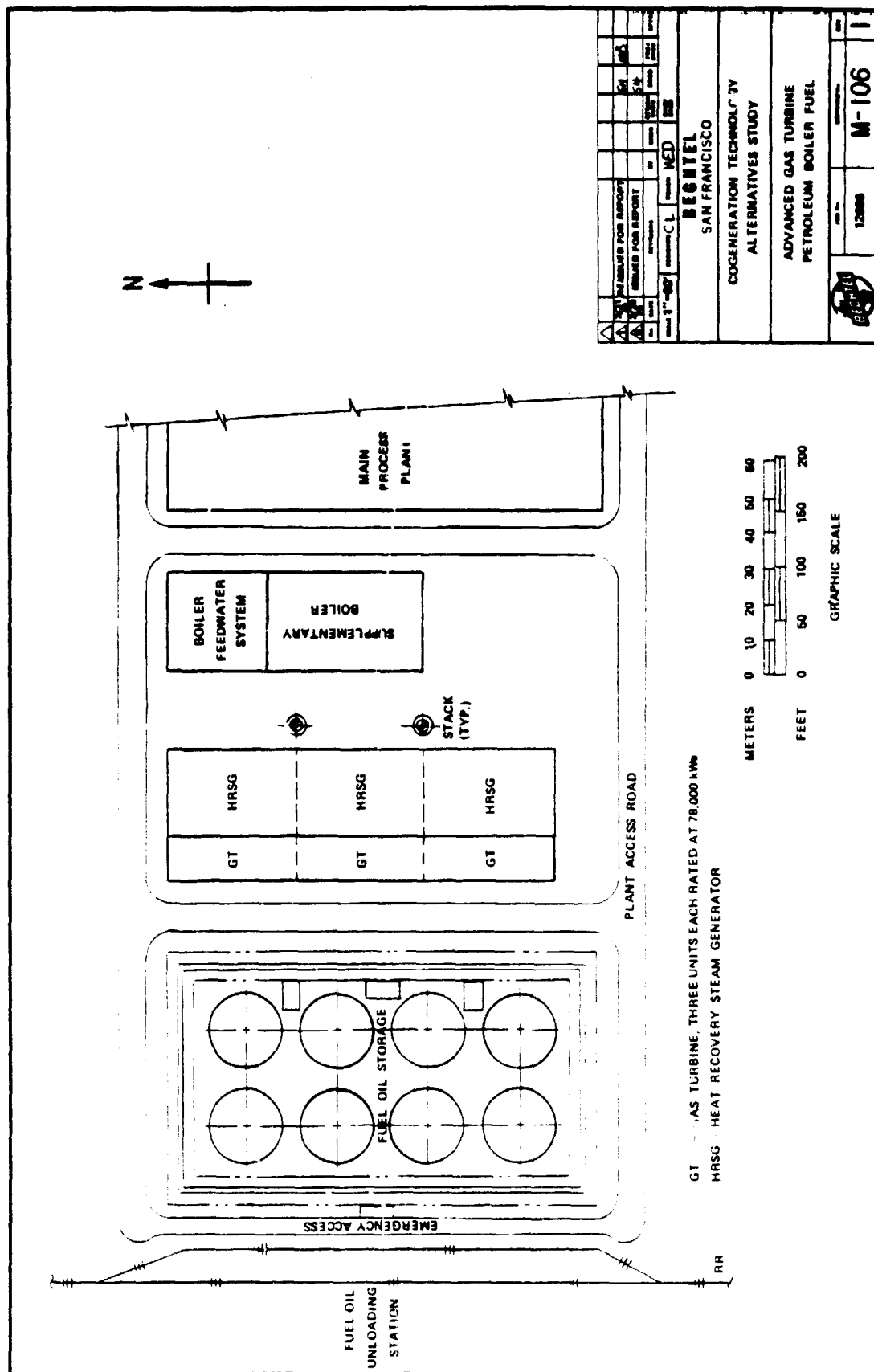


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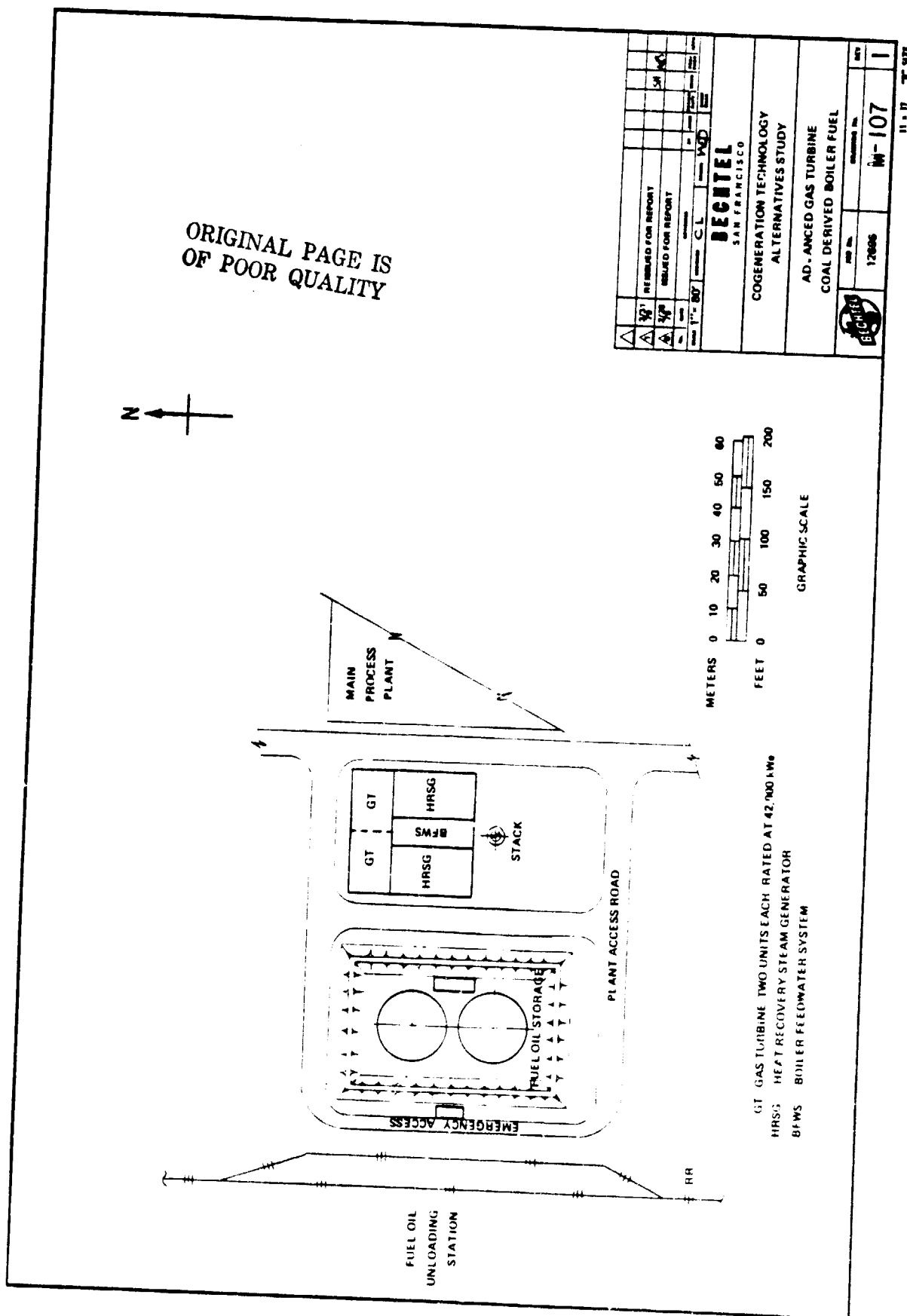


Figure IV-88

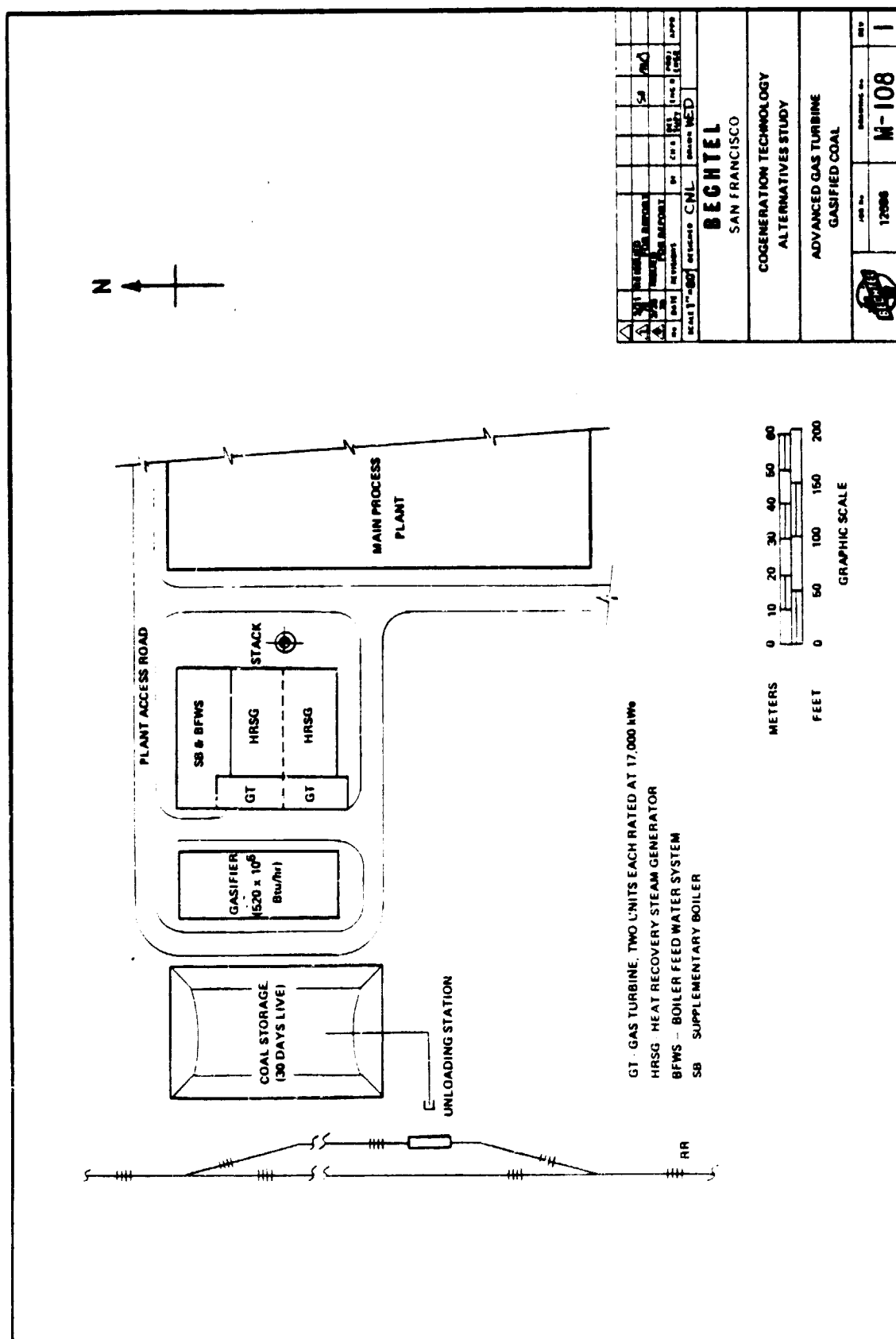


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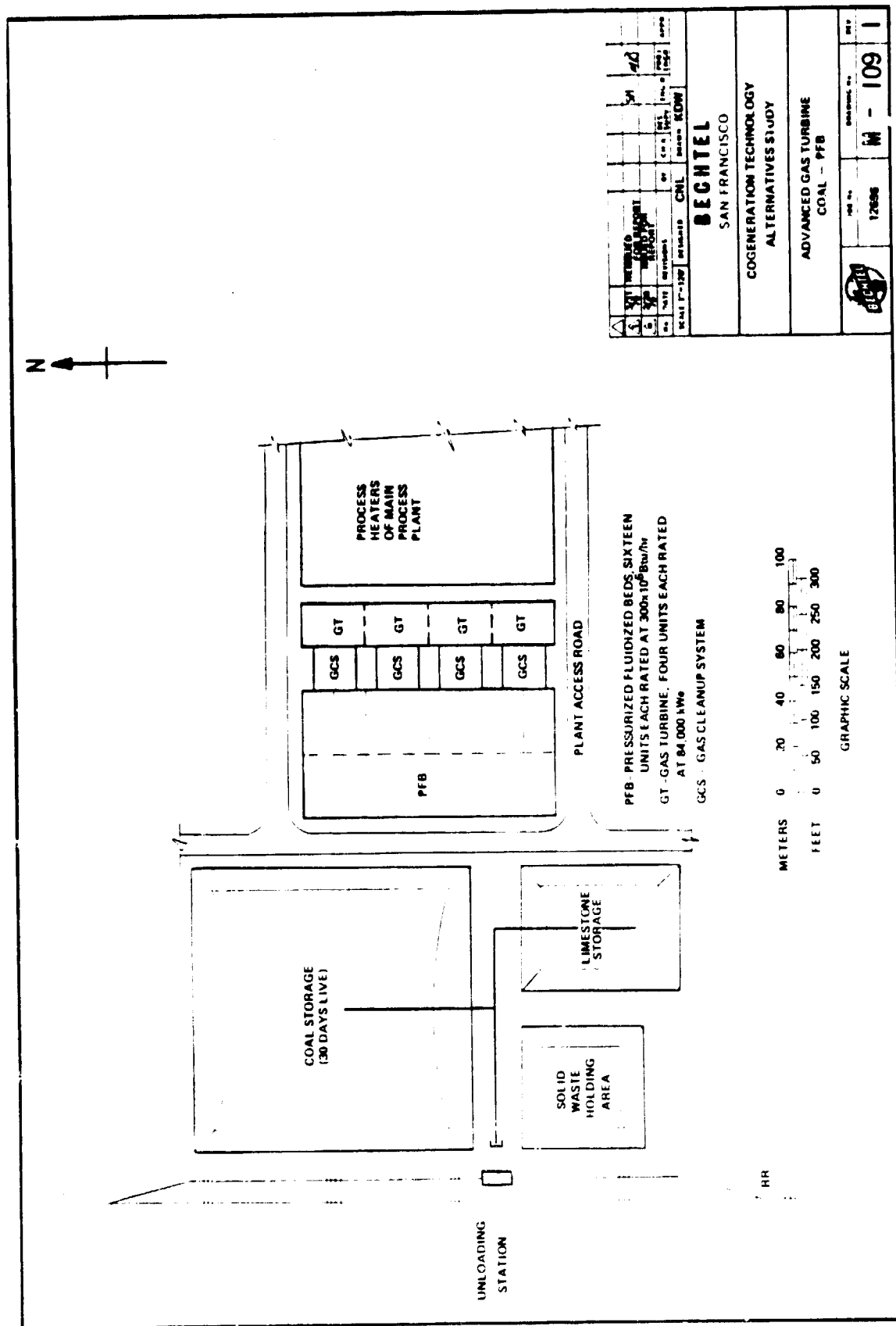


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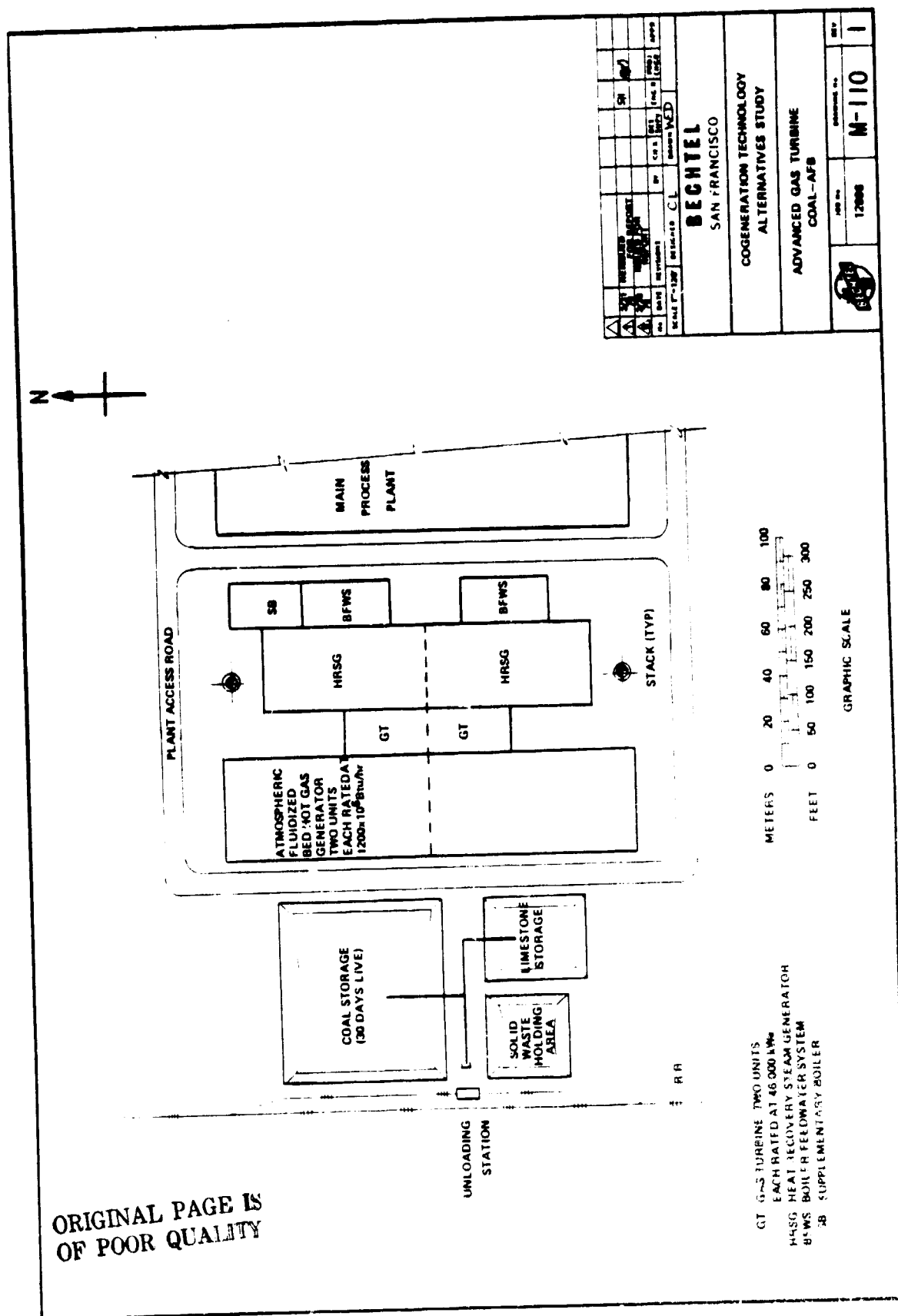


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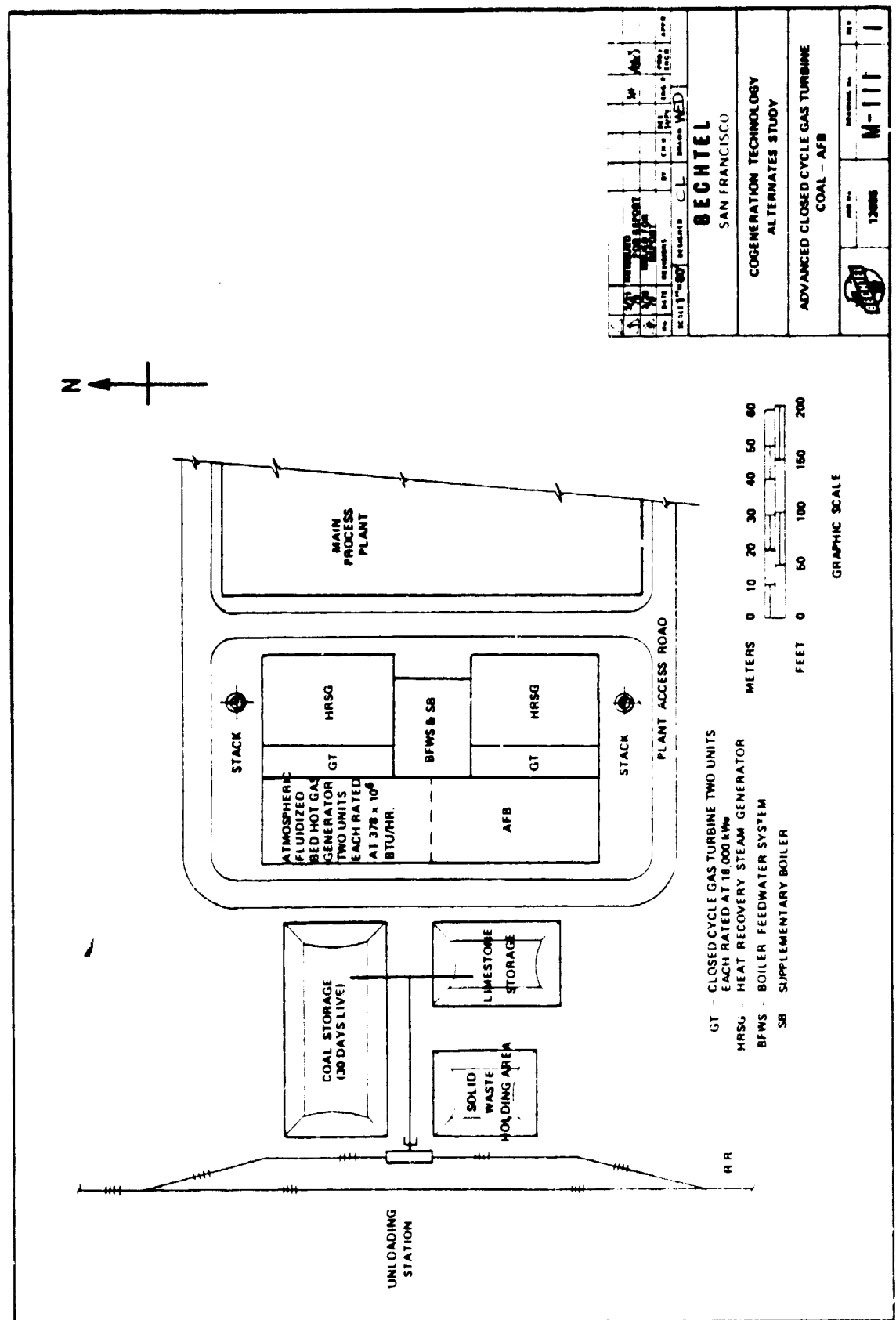


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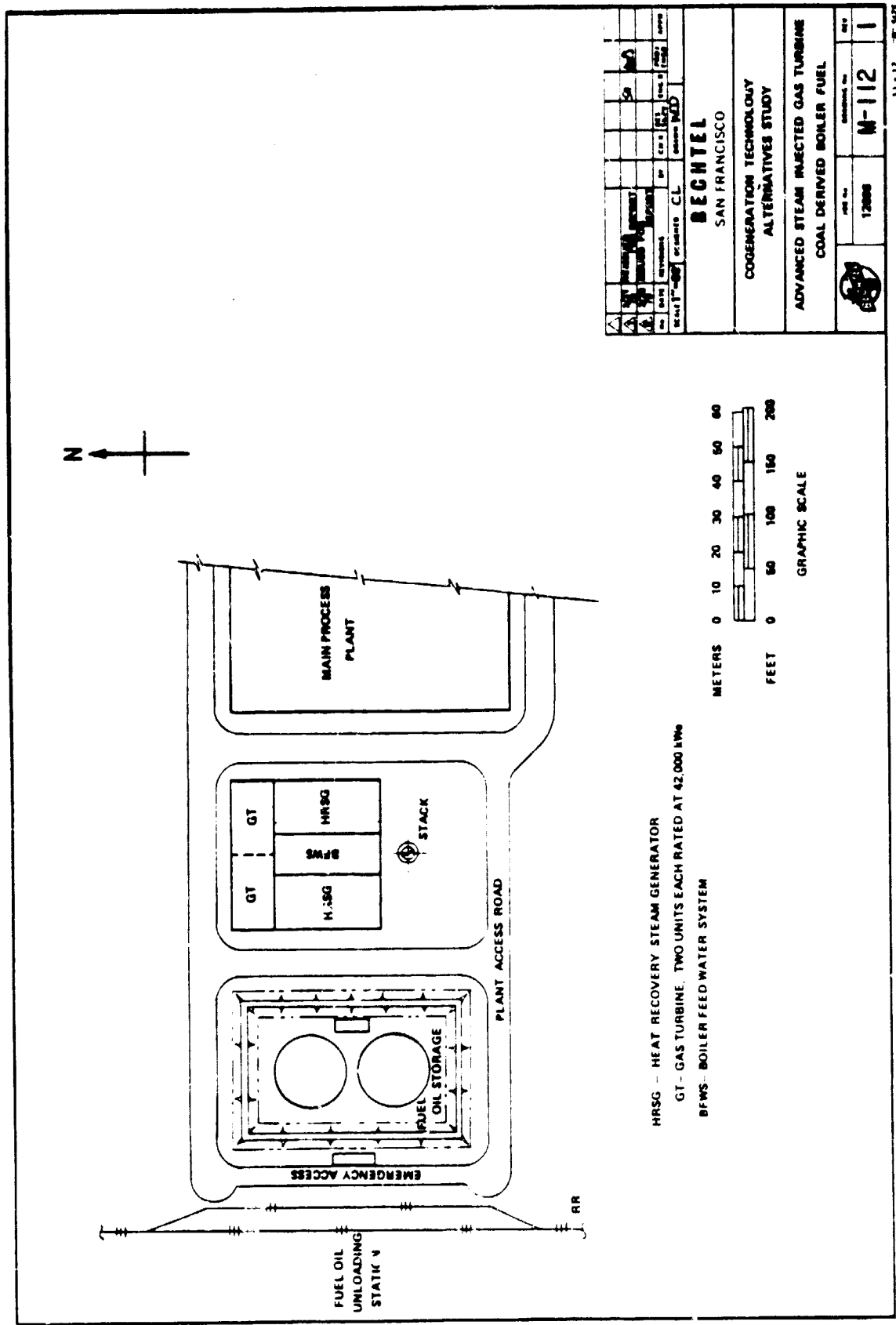


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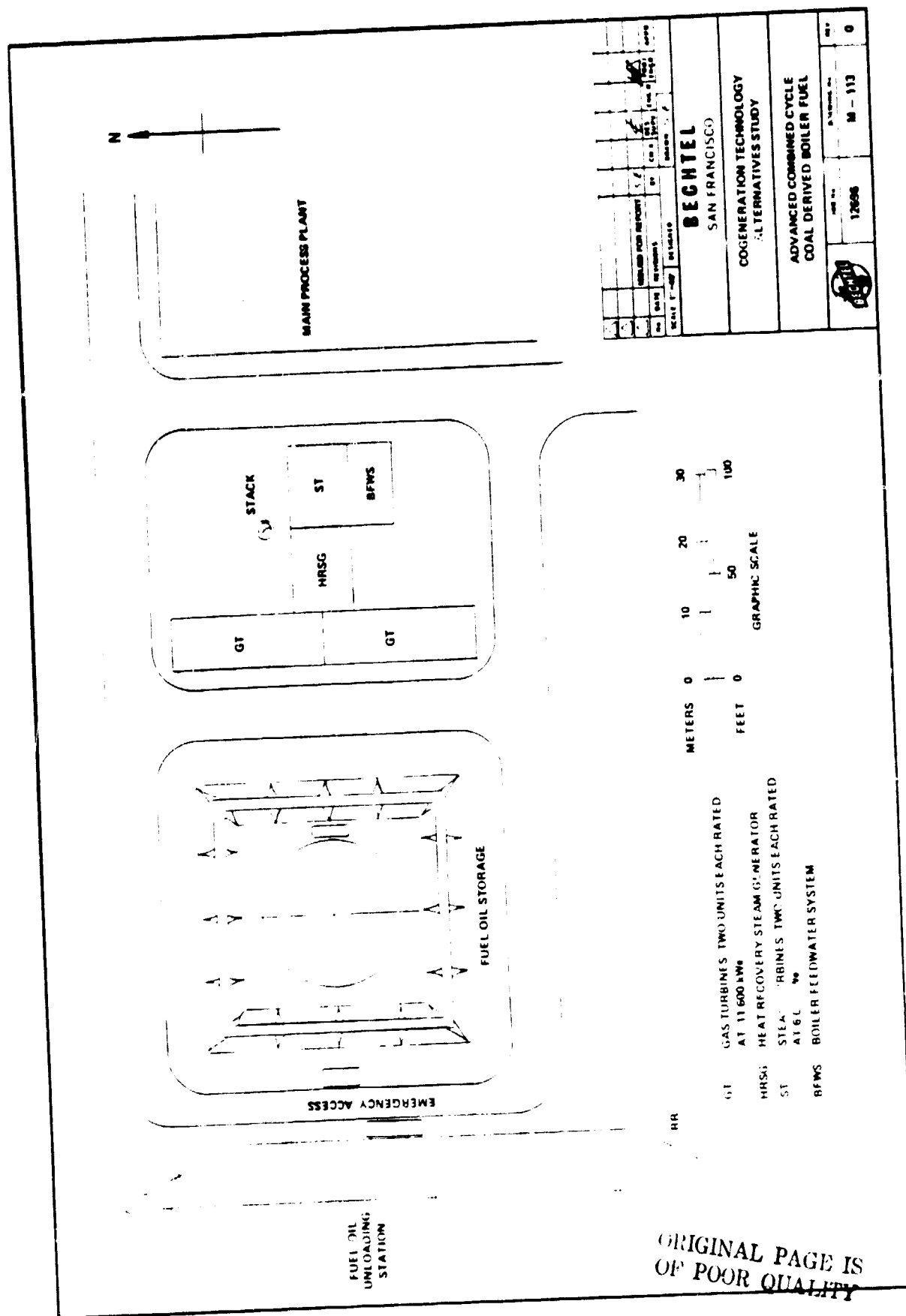


Figure IV-94

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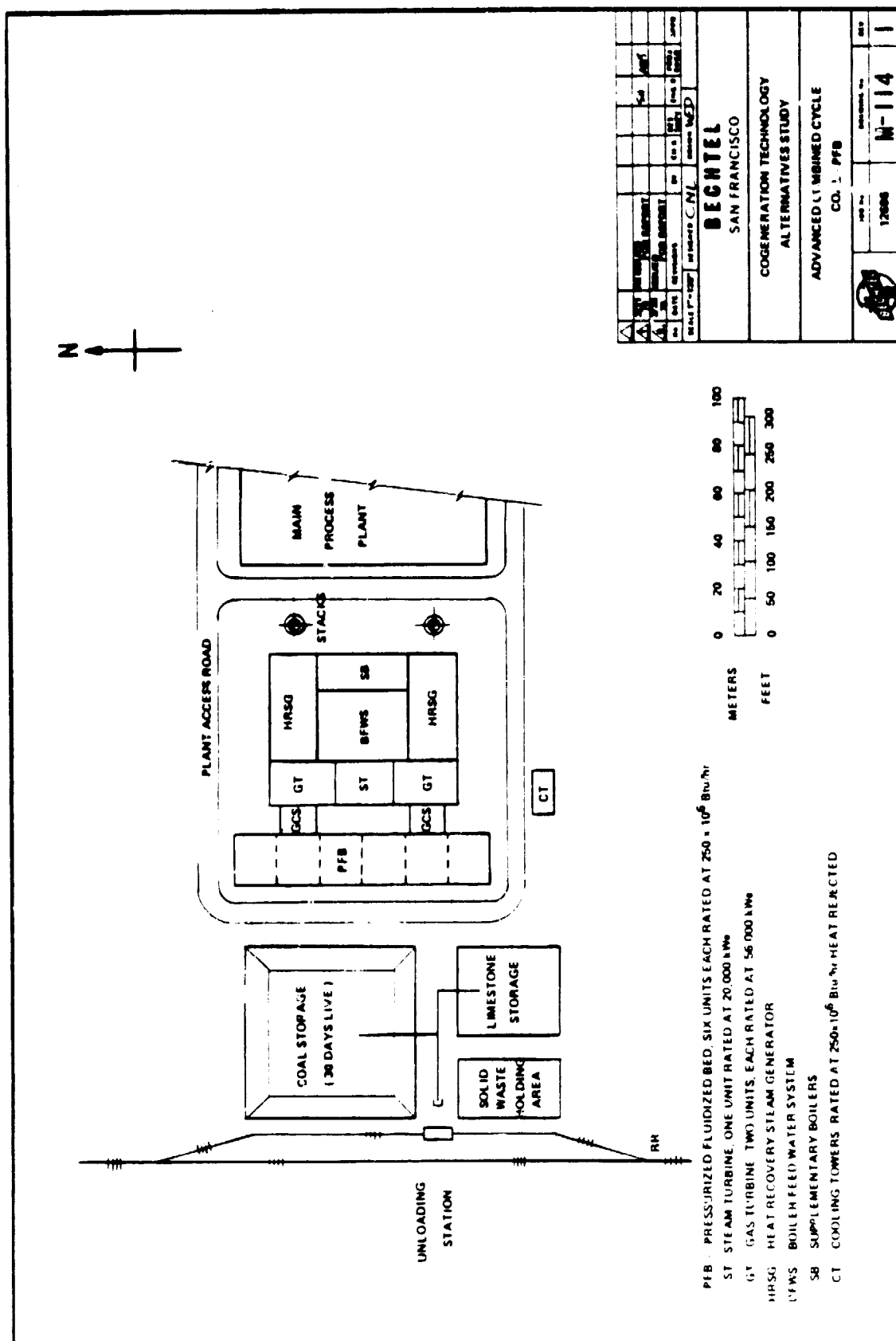


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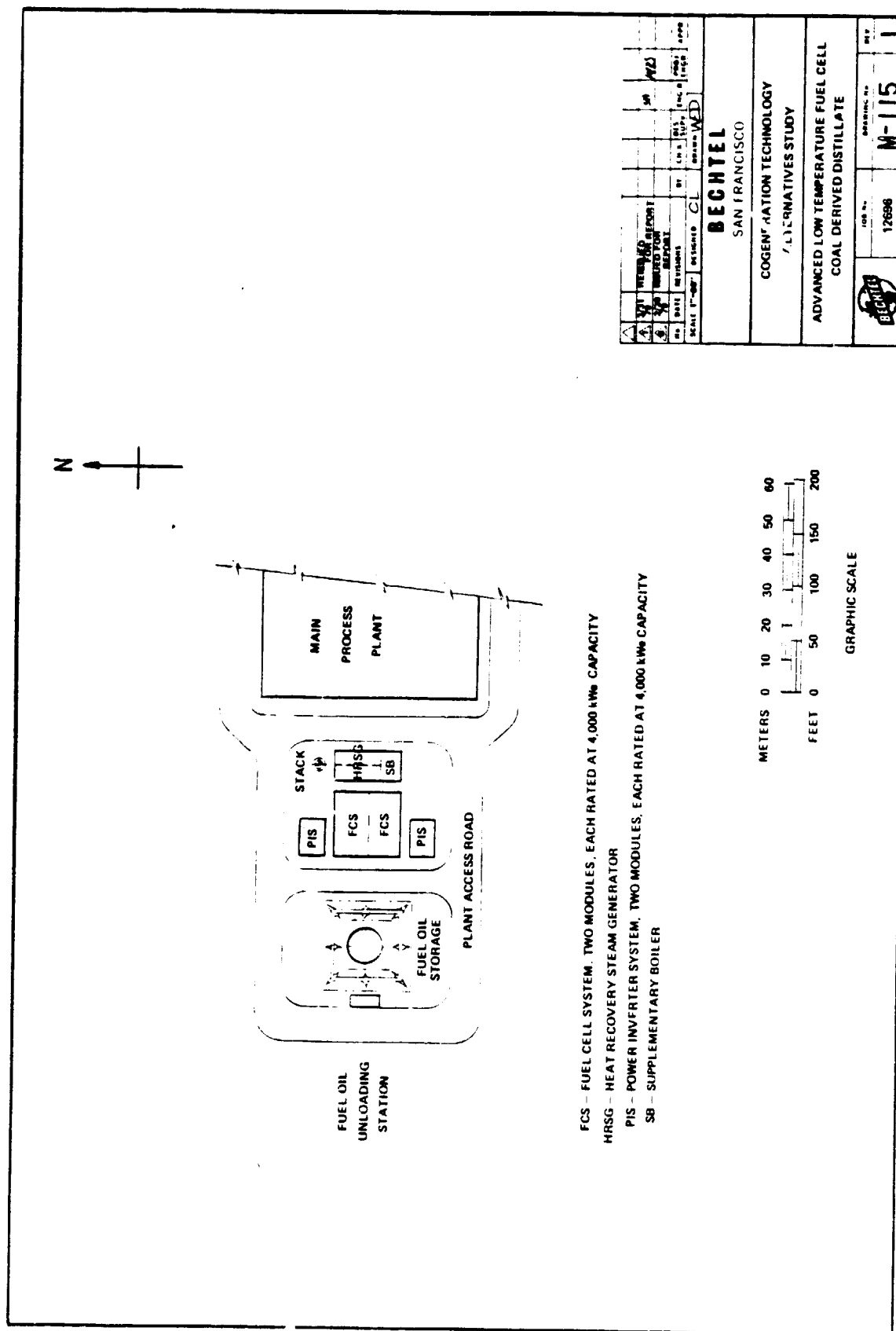


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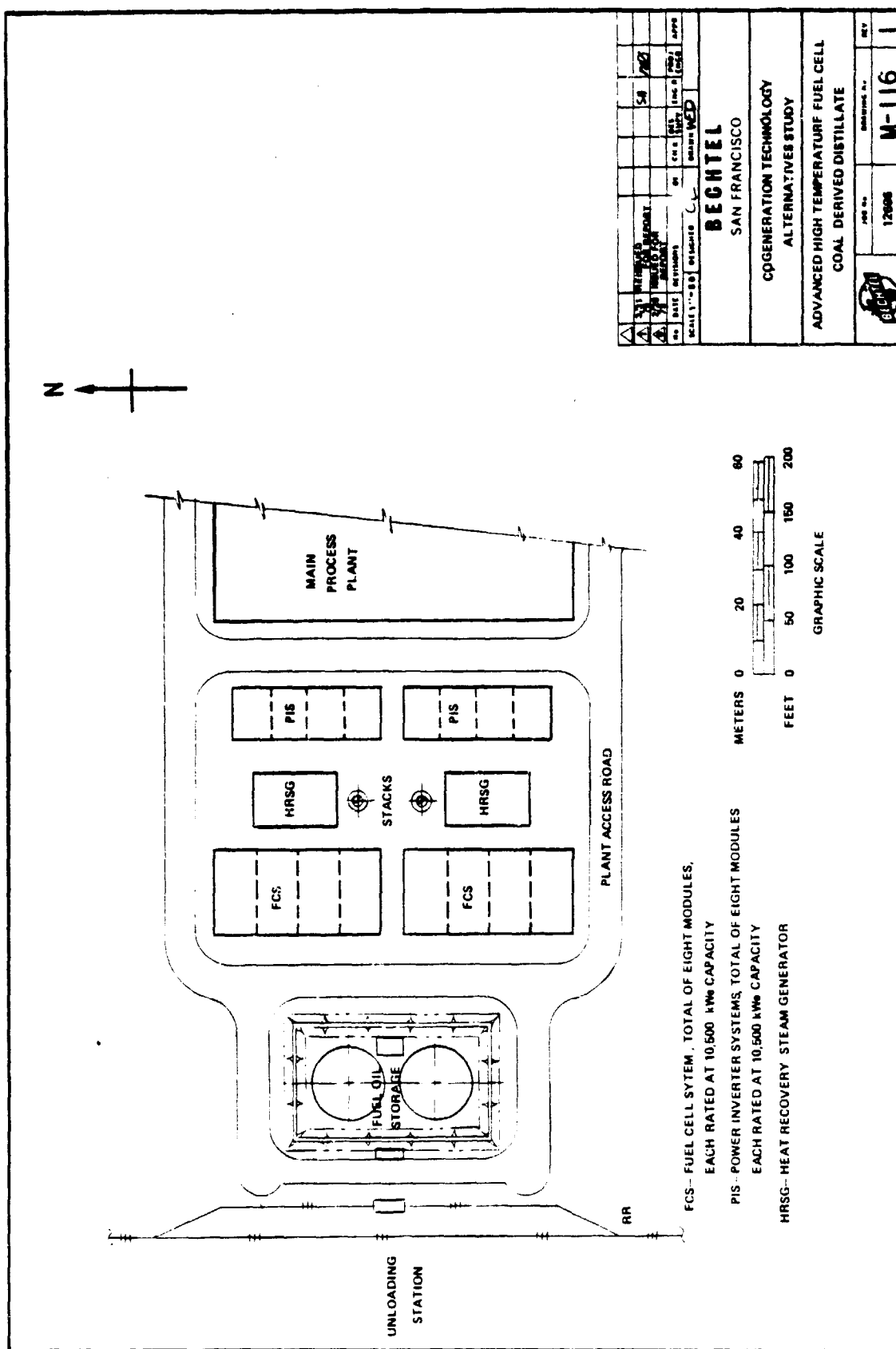


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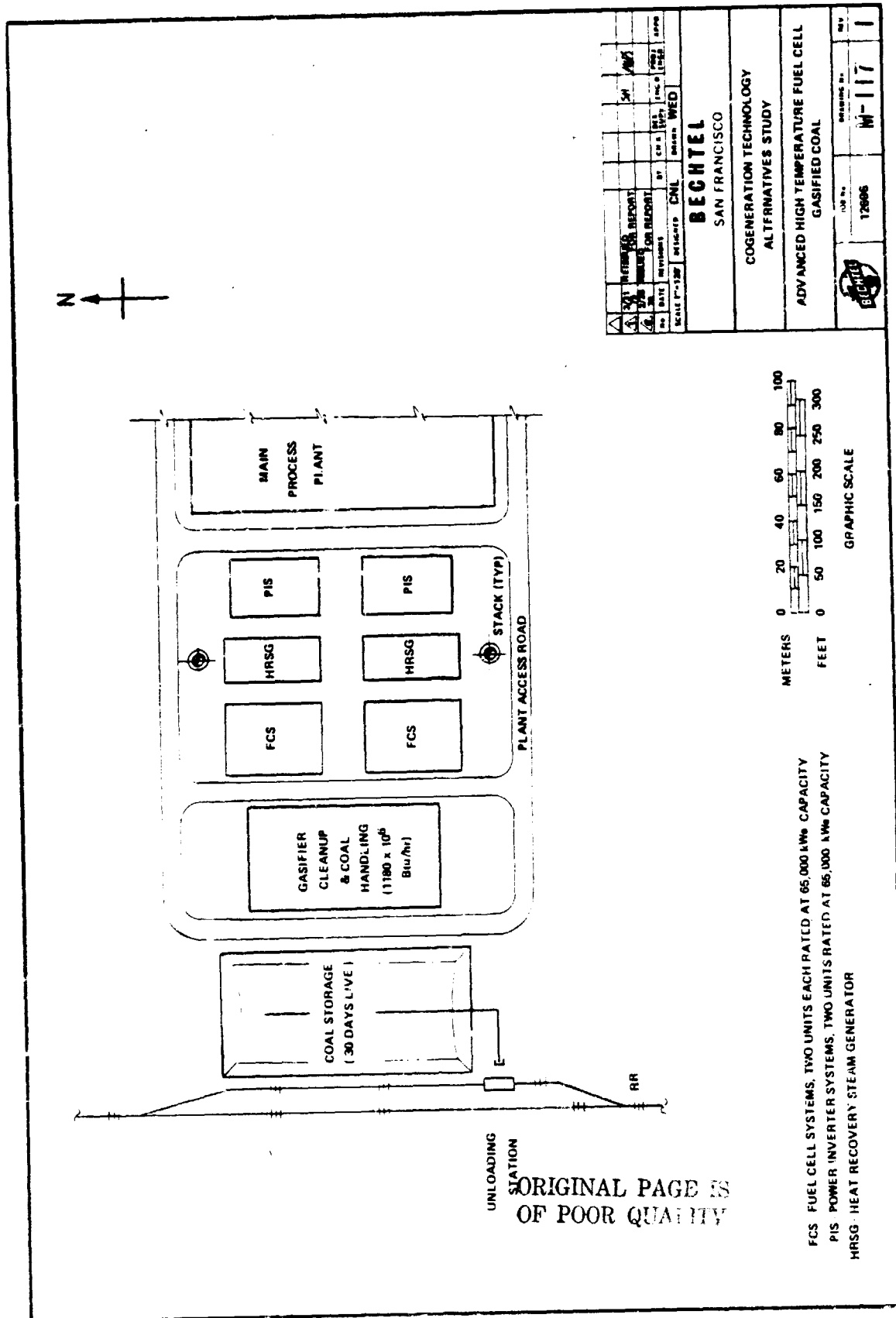


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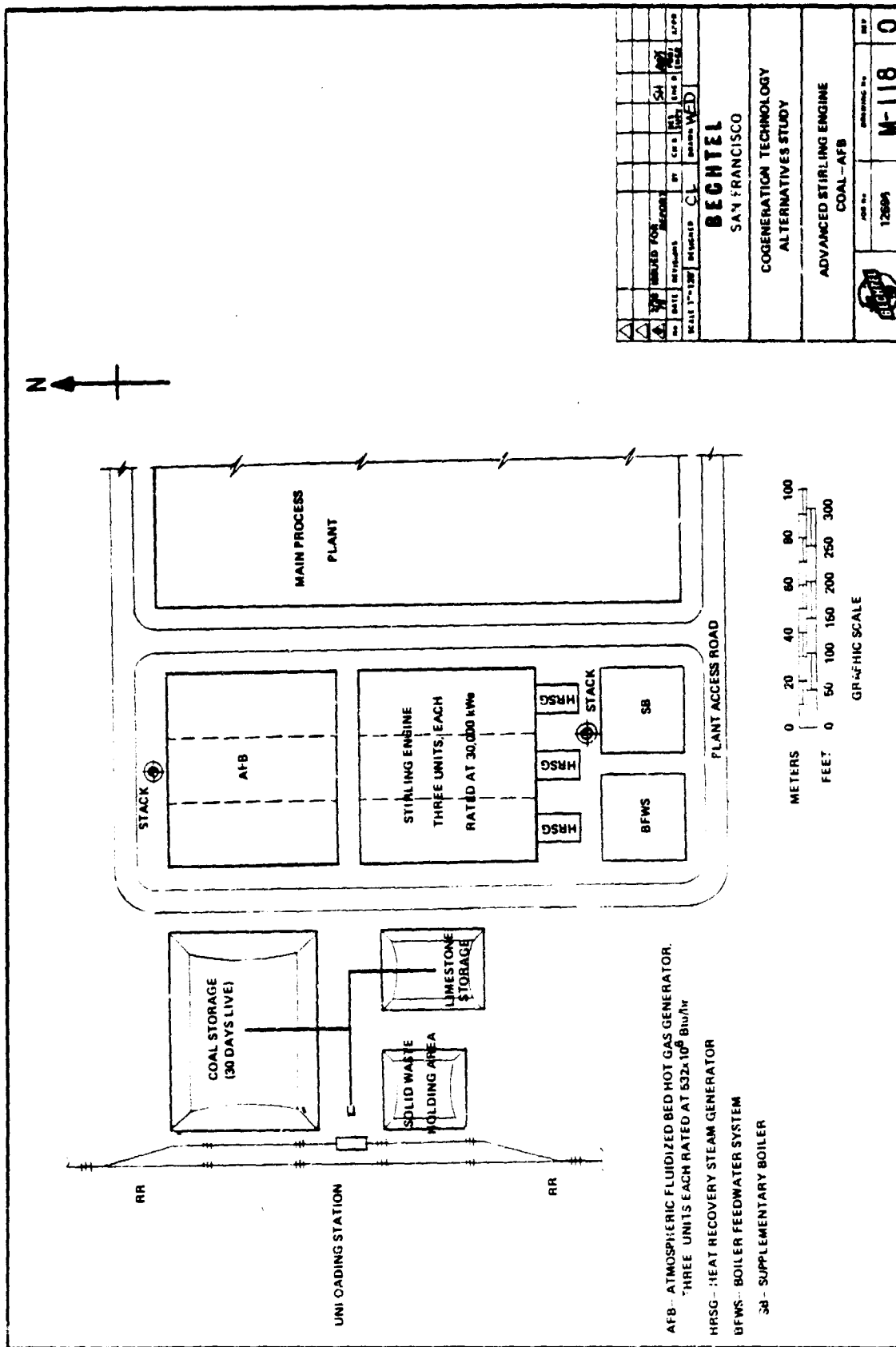


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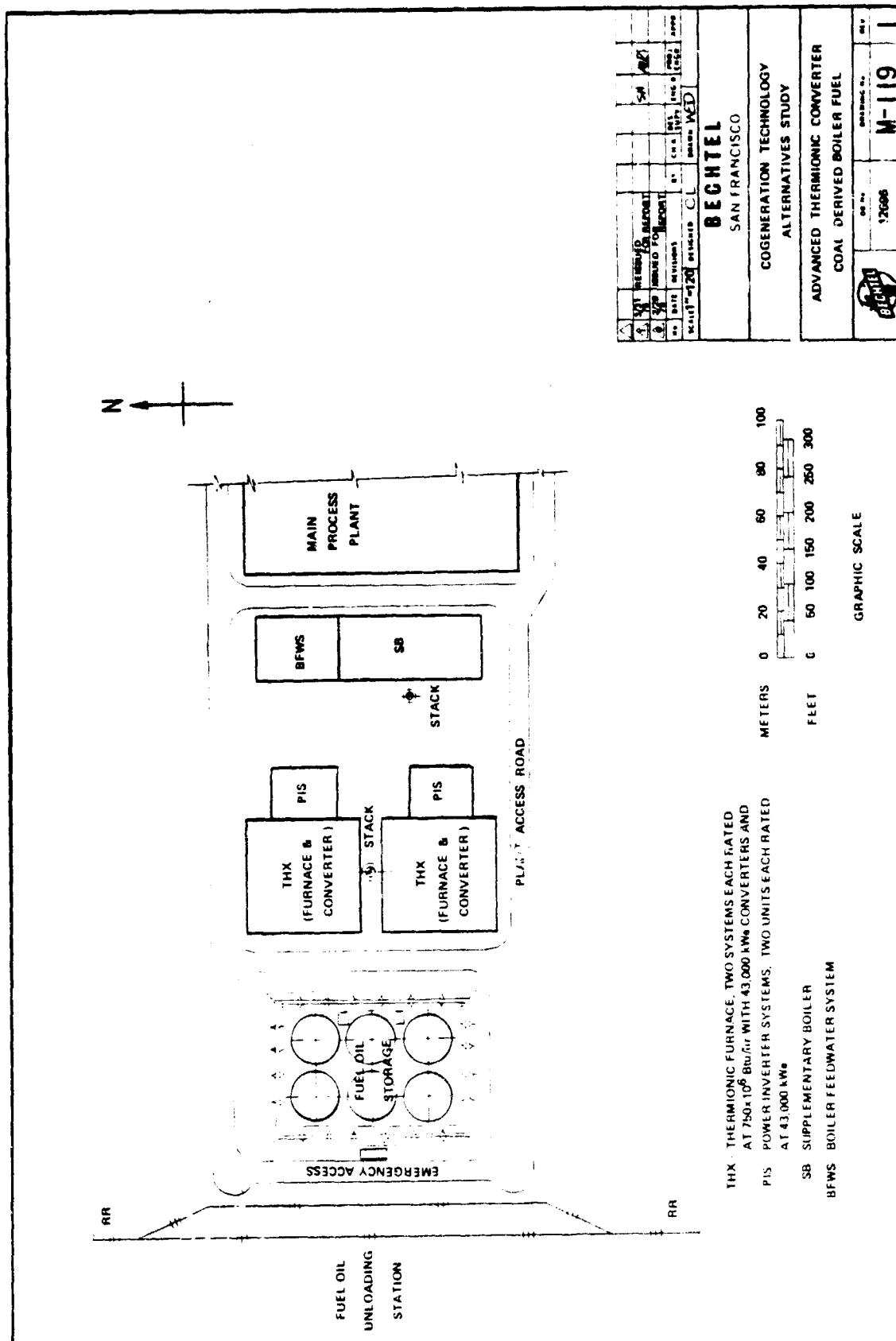


Figure IV-100

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